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IDENTIFYING AND DETERMINING SKILL DEGRADATIONS OF PRIVATE AND COMMERCIAL PILOTS

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16. Abstract

The aeronautical skills of a sample of non-instrument rated, private and commercial pilots, were studied to determine the effect of experience factors. A sample of 55 pilots, chosen to be representative of the total pilot population in terms of age and experience, each flew three flights with an evaluator in a Cessna 150. On the average, subjects received higher scores on skills employed most often. They received the lowest average scores on skills seldom practiced such as stalls and simulated instrument flight. A step-wise regression analysis indicated that an individual's latent skill accounts for 30% of the variance between pilots. Experience factors accounted for 25% of the variance. The most predictive of these experience factors were Recency and the logarithm of total time. Recency is the average rate at which a pilot flies. It is the most important experience factor and the one which the pilot can vary most easily. The logarithm of the total time was the second most important experience factor. The logarithmic dependence causes changes of total time to be more important for pilots with low total time. Skill degradation with years since certification was the third most important experience factor. A .15 hour per week increase in flying Recency or a 10% increase in total time is required to offset the effect of a year since certification.

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PREFACE

This final technical report covers the research performed under Department of Transportation, Federal Aviation Administration, contract DOT-FA72WA-2767 during the period April 20, 1972 to July 5, 1973.

The work was accomplished by researchers from the Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, Measurement Systems Laboratory and Man-Vehicle Laboratory. Significant assistance in support of flight operations was received from Charles L. Collins, Director, Charles Stark Draper Laboratory Flight Facility, and his secretary Shirley L. Grady. Mark Hannig, Paul Raila, and Ted Han contributed to the organization and preparation of the flight data for analysis. Professor William Rand of M.I.T. provided technical advice on the statistical analysis.

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SUMMARY

The major result of this work has been to quantify on a statistical basis the variations in skill among non-instrument rated private and commercial pilots. Variations between pilots of the population due to individual differences in their latent skill accounts for 30% of the observed variance. Variations due to quantitative experience factors accounts for 25% of the variance. The remaining 45% is due to random variations of individual pilots, interaction effects and noise in the measurement process.

The variations due to experience factors can be represented by a regression model. This is an equation which predicts average skill score based on Recency in type, logarithm of the total time, years since certification, and logarithm of the time in type. Each of these factors contributes linearly to the overall skill score in an additive way. The equation which relates these experience factors to skill is based on an observation of the pilot population. It has not been shown that a change in these factors causes a change in the skill of an individual pilot. However, it is probably reasonable to assume that it does, and this assumption is required in order to apply the equation in practise. The equation tells us that pilots who have either:

.4 hrs/week more type recency, or
32% more total time, or
3.3 fewer years since certification, or
150% more time in type,

have on the average a 0.1 skill unit higher overall grade. (The standard deviation of the overall grade was 0.7 skill units.)

The most important of these experience factors was Recency. It accounted for the largest percentage of the variance (40% of the contribution of all the experience factors combined). It is the experience factor which can be varied most easily. (A single four hour flight will increase Recency by one hour per week. Recency will decay exponentially to zero with a time

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constant of four weeks with no flying.) The second most important experience factor was the logarithm of the total time. It accounted for the next largest percentage of the variance (28% of the total for all experience factors). The logarithmic dependance causes changes in total time to be more important for pilots with low total time. These results are valuable for helping pilots to appreciate the importance of total and recent experience.

The results of the study are also pertinent to the analysis of recent changes in Part 61 of the Federal Air Regulations. Consider the requirement for a periodic flight review on the basis of a linear decrease in skill with years since certification. The current average for this population is about six years since certification. Make the assumption that a biennal flight review will reduce the effective average to near one year. The five year reduction accounts for a .15 average skill unit increase. Making the flight review an annual requirement would only increase the average skill by an additional .015. It appears that the biennal review is helpful but that requiring it more often than every 2 years would result in diminishing returns. Pilots do not like to take check rides, but such flights can be effective in improving skill. Anticipation of the flight review should cause pilots to schedule preparatory flights - thus increasing their recency, if nothing else.

Concerning the reduction in the requirement for landings in the last 90 days from five to three, the following applies:

This study suggests recent flight experience to be the most important experience factor considered to explain observed skill. The effect of experience 90 days old on Recency as defined in this study is near zero. Furthermore, three landings per 90 days correlates with a flight time of only 1.5 hours in 90 days. This amount of flight time would have a negligible effect on average skill.

In order to bring a pilot with degraded skills back up to standard, it is necessary to increase the recency in proportion to the skill degradation. The ratio of the two suggests that

.15 hour/week recency is required to offset the effect of each year idle. If this recency is acquired all at one time, then the requalification of a degraded pilot should require 0.6 hours of flight for each year spent with no flying. Although flying skills degrade rapidly when not used, they return rapidly with practice.

Individual differences in latent skill are more important than experience factors in predicting overall skill scores. The results of written quizzes are not effective in predicting flight test results.

I INTRODUCTION

The purpose of this work was to measure skill degradation of non-instrument rated, single-engine, FAA certificated private and commercial pilots. Selectees from the pilot population were tested to determine the measurable and recent experience factors which are important for the maintenance of aeronautical skills within this profile. The program was designed to measure the statistical relationship between skill and specific experience factors.

The sample for testing was selected from the total population of FAA certificated private and commercial pilots who were single-engine airplane rated.

A mailing list of one thousand pilots was assembled from the FAA Airmen Directory File by selecting every 10th pilot from those pilots with addresses in the New England states. Letters (Appendix A-1) were mailed to this group inviting them to participate in the flight test program. The statistical characteristics of the pilots on the mailing list was checked against the statistical characteristics known about the total pilot population (References 1 and 2) to ensure the list was representative.

A sample of seventy-one pilots was selected from those 324 who returned the Pilots' History Questionnaire (Appendix A-2) and indicated willingness to participate in the flight test program. The statistical properties of the sample of the 71 pilots were also checked against characteristics known about the total pilot population (References 1 and 2). In addition, the returned questionnaires provided a measure of actual flight recency and the pilots' opinions concerning their own skill degradation.

An objective type flight test was adapted from an Embry Riddle Study described in Reference 3. The flight test procedure was the same, but the grading was modified in that a numerical grade on the various phases of each flight was substituted for the long binary check list previously used.

Flights were conducted in a Cessna 150 based at the M.I.T., C.S. Draper Laboratory Flight Facility at Hanscom Field, Bedford, Massachusetts. The testing was conducted by five instructor pilots from M.I.T.

The standard program was as follows:

1st meeting:
- -Brief on program
- -Complete subjects' Experience Data Form
- -Short written quiz on aeronautical knowledge
- -First flight test of aeronautical skills (Basic Piloting)

2nd meeting:
- -Short written quiz on aeronautical knowledge
- -Plan cross-country flight to destination and return
- -File VFR flight plan
- -Conduct cross-country flight

3rd meeting:
- -Normally one month after second flight
- -Test aeronautical skills (repeat first flight)
- -Review evaluation of aeronautical skills and knowledge with subjects tested

Each maneuver or phase of flight to be evaluated was identified by the type of skill that was primarily involved. The skill types considered were:

Procedural Skills (retention and recall)
Judgement and Problem Solving
Motor Coordination

Each subject's performance on each phase of each flight was graded on a continuous scale from 0-5 which had the following interpretation:

5 perfect
4 above average
3 average
2 below average
1 unacceptable
0 dangerous

Each subject was also given one score that represented the examiner's evaluation of the subject's over-all aeronautical skill and knowledge.

The record of all scores has been kept separate from the names of the subjects for confidentiality.

Data processing was performed to show statistically from the measurements how skill varied as a function of the following factors known about each subject:

- -Total Flight Time
- -Recency (current hrs/week)
- -Time in Type (Cessna 150)
- -Time since Certification (years)
- -Type Initial Training (Military, FAA Approved School, etc.)
- -Type of Flight Operations Conducted (Controlled Air Field vs. Uncontrolled Air Field)
- -Age
- -Gender
- -Geographic Location of majority of flights

II THEORY

The variations in observed piloting skill can be considered to be due to several causes classified as follows:

1. Variation due to the fact that the latent skill of each individual is different, independent of previous experience.

2. Variation due to quantitative factors which describe the subjects' experience, such as Total Time, Recency, Age, Years Since Certification, etc.

3. Variation in measured skill due to a) the observer, b) the measurement process, or c) interaction effects between experience, observer, and measurement factors.

4. Random variations in the demonstrated skill of an individual subject not accounted for by the foregoing.

Most flight checks have the purpose of evaluating overall skill without attempting to differentiate among these four groups. In this study, the emphasis has been placed on measuring skill variations due to factors in the second group. A major problem in such testing, however is that the sources of variation due to the other, primarily non-experience related groups have been found by this study to be at least as important. Thus, although the effects of the experience factors have been measured, and can be considered known with a reasonable degree of statistical reliability, at least for the test population, knowledge of second group factors is of only limited value in predicting overall skill due to variation introduced by other components. For example, statistical analysis of the test data in this study indicates that the first group of factors accounts for about 30% of the variance in the data. The second group of experience factors accounts for about 25%. The remaining 45% is due to groups 3 and 4.

Measurement of Experience Factors

Certain aspects of an individual pilot's experience can be easily represented directly by single parametric variables. Examples include Total Time, Total Time in Type, Age, Years Since Certification, etc. However, development of a quantitative parameter which summarizes an individual pilot's recent flight experience in a reasonable way is a more difficult problem. Since it was expected that the nature of an individual's recent flight experience would heavily influence his aeronautical skills, it was decided that an attempt at parametric representation of recent flight history should be made, for the purpose of this study.

The method chosen was to define a parameter called "recency" which can be calculated for an individual subject given his recent flight history. Actually, four different kinds of recency were defined:

Total Recency (hrs/week)

Type (Cessna 150) Recency (hrs/week)

Landing Recency (landings/week)

Type (Cessna 150) Landing Recency (landings/week)

These "recency" parameters were constructed mathematically so as to have the following useful properties:

1. For a subject who practiced regularly at a constant rate, his values of recencies would be equal to his practice rates.

2. If the subject stopped flying altogether, his values of recency would decay away exponentially to zero over a characteristic degradation time.

(Total Recency can be conceptualized as the result of passing the instantaneous rate of change of total time through a low pass filter with a time constant equal to a characteristic skill degradation time.)

A mathematical approach to the recency concept is given in Appendix B.

SUBJECT: DATES = JULIAN

TOTAL TIME : 250
C-150 TIME : 50
RECENCY : 0
LNDG RECENCY : 0
C-150 RECENCY : 0
C-150 LNDG REC. : 0

FLTS IN '72: 8

FLIGHT = 8	DATE : 098	DUR : 2.0	# LNDGS : 2	C-150? : Y
FLIGHT = 7	DATE : 099	DUR : 1.0	# LNDGS : 2	C-150? : Y
FLIGHT = 6	DATE : 155	DUR : 1.0	# LNDGS : 2	C-150? : N
FLIGHT = 5	DATE : 177	DUR : 0.8	# LNDGS : 5	C-150? : N
FLIGHT = 4	DATE : 183	DUR : 0.7	# LNDGS : 2	C-150? : N
FLIGHT = 3	DATE : 184	DUR : 0.7	# LNDGS : 2	C-150? : N
FLIGHT = 2	DATE : 207	DUR : 0.7	# LNDGS : 2	C-150? : N
FLIGHT = 1	DATE : 223	DUR : 0.8	# LNDGS : 1	C-150? : Y

TEST FLIGHT = 1
DATE : 267 DUR : 1.6 # LNDGS : 5

TOTAL TIME = 258
TOTAL C-150 TIME = 54
RECENCY = 0.10
LANDING RECENCY = 0.23
C-150 RECENCY = 0.04
C-150 LNDG REC. = 0.06

OF INTERFLIGHTS : 1

INTERFLIGHT # = 1
DATE : 271 DUR : 1.75 # LNDGS:2 C-150?:Y

TEST FLIGHT = 2
DATE : 295 DUR : 2.0 # LNDGS : 2

TOTAL TIME = 261
TOTAL C-150 TIME = 57
RECENCY = 0.37
LANDING RECENCY = 0.76
C-150 RECENCY = 0.35
C-150 LNDG REC. = 0.69

OF INTERFLIGHTS : 0

TEST FLIGHTS = 3
DATE : 309 DUR : 1.1 # LNDGS : 5

TOTAL TIME = 263
TOTAL C-150 TIME = 59
RECENCY = 0.53
LANDING RECENCY = 0.76
C-150 RECENCY = 0.52
C-150 LNDG REC. = 0.72

EXAMPLE RECENCY CALCULATION

Figure 1.

An example showing how an individual's values of recency are determined by his recent flight history is shown in Figure 1 (see also section IV: Analysis).

The general approach used in the data analysis was as follows: Given a parametric representation of a pilot's skill (his overall flight check grade), a multidimensional regression analysis was used to determine the effects of "group 2" experience factors, including recencies, on the mean grade of the sampled population. Theoretically, it might have been possible to analytically estimate an "optimal" value for the characteristic degradation time constant of recency by iteratively fitting a regression model for skill to different sets of data generated by assuming different values of recency time constant, and defining the "optimal" time constant to be that which minimized the variance in the overall model. However, such an approach was not chosen because the quality of the final regression fit was not expected to vary significantly for large changes in the recency time constant. This was because many of our pilots flew regularly (for these individuals, the assumption of a particular time constant does not affect the value of calculated recency). Also, in most cases, the testing program was unable to significantly perturb the recency parameters of individual pilots unless the time constant was assumed to have unrealistically small values. Given this situation, the overall objectives of the study, and the order of magnitude increase in complexity of the data analysis which such a search procedure would require, an alternative method for estimation of the recency time constant was adopted. This consisted of basing our recency calculations on an estimate of the time constant furnished by the pilots themselves. This estimate was obtained by taking the answer to a carefully chosen question asked of all subjects tested as well as all those contacted by mail in the original survey of the New England region:

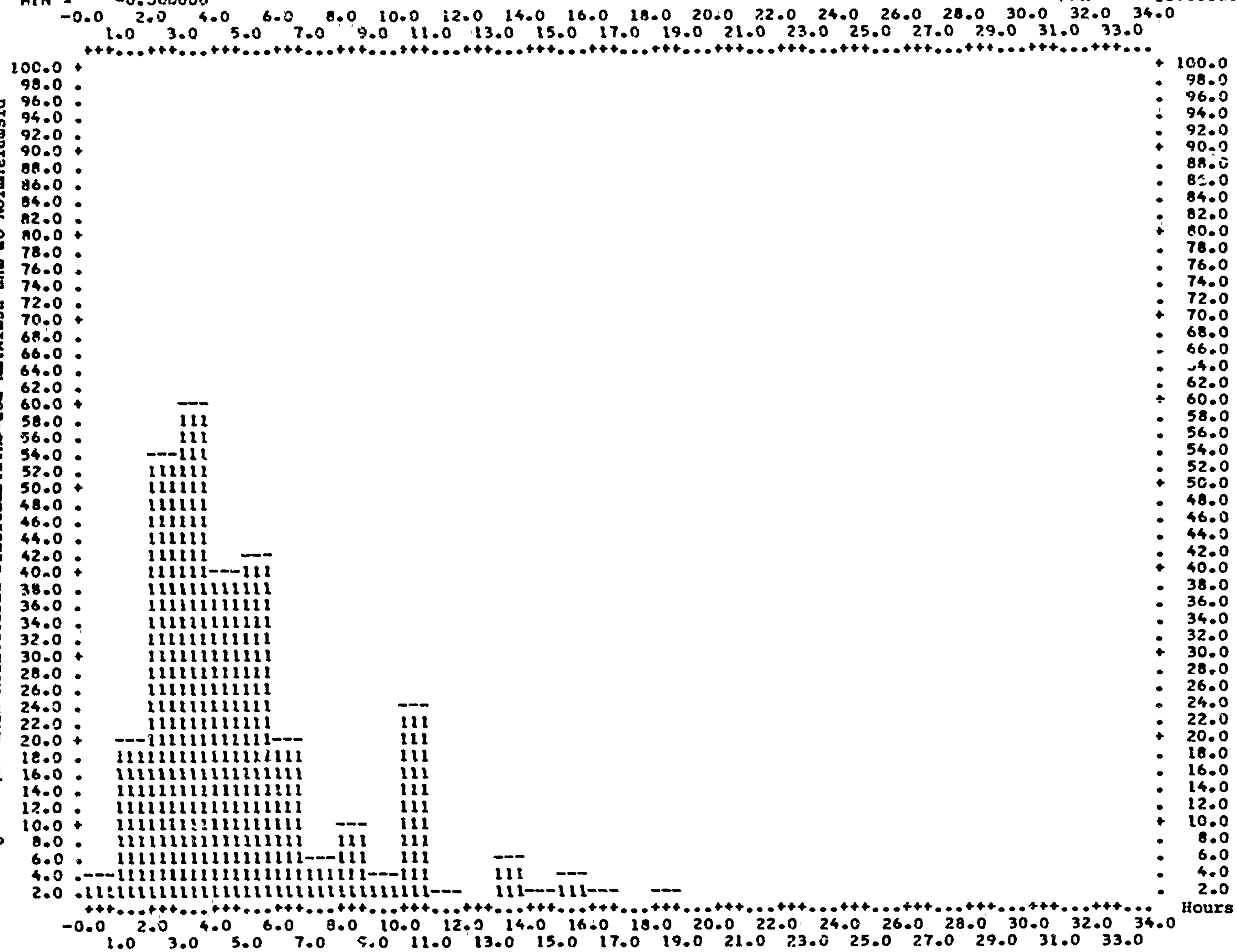
> "Assume that you were flying regularly at the rate of one hour per week and that you stopped all flying for a period of six months. How many flight hours would you estimate you would need in order to regain your former pilot proficiency?"

The answer to the question in hours is a measure of the subject's estimate of his own characteristic degradation time (τ) in weeks. The median value of τ from this measure was three weeks. The mean value was 4.6 weeks. The distribution was skewed and very broad as shown in Figure 2. As a result, it was decided that the definition of Recency would be made using a value of τ of exactly four weeks for all pilots.

BMD05D GENERAL PLOT - INCLUDING HISTOGRAM - REVISED JANUARY 30, 1970
HEALTH SCIENCES COMPUTING FACILITY, UCLA

HISTOGRAM PILOT'S ESTIMATE OF TIME TO REGAIN PROFICIENCY (RECENCY)

HISTOGRAM OF VARIABLE 1
MIN = -0.000000 MAX = 18.000000



DISTRIBUTION OF THE ESTIMATE FOR CHARACTERISTIC DEGRADATION TIME Figure 2

III FLIGHT TESTING

Flight testing operations were conducted from a Flight Operations Center established at the M.I.T., C. Stark Draper Flight Facility located at Hanscom Field, Bedford, Massachusetts. All flight testing was done in a Cessna 150 aircraft.

Flight testing was scheduled during the period September 1972 through March 1973, seven days per week when feasible. During this period a total of 381 program flights were scheduled. Flight cancellations due to weather totaled 148 (39%) and 52 (14%) for other reasons (no shows, illness, etc.). In all, 53% of all scheduled flights were cancelled for reasons beyond the control of the Flight Operations Center.

Evaluators

Five experienced pilots from M.I.T. were assigned as evaluators for the flight testing program. A breakdown of their flight experience is as follows:

AGE	FAA CERTIFICATE	RATINGS--FLIGHT EXPERIENCE
24	Commercial Pilot	Airplane SEL, MEL Instruments Flight Instructor Ground Instructor (Advance, Instruments) 950 Hours Total Time
35	Commercial Pilot	Airplane, SEL Instruments Flight Instructor Ground Instructor (Advance, Instruments) 1200 Hours Total Time
41	Commercial Pilot	Airplane SEL, MEL Instruments Flight Instructor 3000 Hours Total Time

AGE	FAA CERTIFICATE	RATINGS--FLIGHT EXPERIENCE
48	Commercial Pilot	Airplane SEL Glider Flight Instructor USN Aircraft Commander MEL and Instrument Instructor 7200 Hours Total Time
53	Commercial Pilot	Airplane SEL, MEL Rotorcraft Helicopter Glider Instruments Flight Instructor Society of Engineering Test Pilots USAF Command Pilot 11,500 Hours Total Time

Evaluator standardization was achieved through discussion periods, standardization flights and the following guidelines:

Skill grades were assigned as indicated on the Flight Evaluation Record form (Figure 3) for major subareas of each flight, plus an overall grade and written quiz grade when taken. A grade was entered in all boxes for which the subjects' performance was observed and a dash if the box was not applicable to the flight or the maneuver was not performed. Grades were assigned on the basis of 0-5 as follows:

5 = perfect
4 = above average
3 = average
2 = below average
1 = unacceptable
0 = dangerous

In general the criteria for "average" was that established by the FAA Private Pilot Flight Test Guide AC 61. Grades were assigned on observed performance in the following three areas:

FLIGHT EVALUATION RECORD

SUBJECT ____________________ HOBBS TACH

INSTRUCTOR ____________________ FINISH ______ ______

AIRCRAFT ____________________ START ______ ______

FLIGHT ____________________ TOTAL ______ ______

QUIZ GRADE ____________________ DATE ____________

OVERALL GRADE ____________________

	Procedures Retention & Recall	Judgement & Problem Solving	Motor Coordination
FLIGHT PLANNING & FILING			X
AIRCRAFT PREFLIGHT		X	X
START, TAXI & RUNUP		X	X
TAKEOFF & DEPARTURE		X	
SLOW FLIGHT	X	X	
STALLS		X	
VOR ORIENTATION & TRACKING			X
SIMULATED ENGINE OUT	X		
SIMULATED LOSS OF HORIZON			
PILOTAGE & DEAD RECKONING			X
CHANGE IN FLIGHT PLAN			X
RADIO PROCEDURES			X

LANDINGS

	Pattern	Accuracy
1st		
2nd		
3rd		
4th		
5th		
6th		

1 3 5 4 3 2 1 0

FLIGHT EVALUATION RECORD
Figure 3

1. Procedures, Retention and Recall

The subject was expected to be knowledgeable concerning FAR, Part 61--Certification: Pilots and Flight Instructors and Part 91--General Operation and Flight Rules. Written quizzes were administered to each subject prior to the first two flights, but evaluators were expected to ask questions and observe the subjects' adherance to specified rules and procedures as required for safety of flight.

2. Judgment and Problem Solving

Grades in this area were based on the subjects' ability to use whatever information was available to him and to apply it as would be expected for his level of pilot certification. Especially important was the subjects' judgment and actions as related to safety of flight.

3. Motor Coordination

The "average" pilot subject was expected to demonstrate the ability to maintain the aircraft in a safe flight attitude under all normal conditions. For all maneuvers, it was required that airspeed be maintained within plus or minus 5 mph, altitude within plus or minus 100 feet and heading within plus or minus 10 degrees. In addition, the subject was expected to be able to quickly recognize unsafe flight situations and to take proper corrective action.

Overall Grade

This was the evaluation of the overall skill and knowledge demonstrated on each flight observed.

Quiz Grades

Two quizzes were administered to the subject. Quiz #1 (Appendix C-1) covered general operating rules and procedures and Quiz #2 (Appendix C-2) covered cross country flight requirements. Quiz questions were typical sample examination questions from Private Pilots' and Commercial Pilots' Handbooks.

Flight Planning & Filing

The subject was expected to file a VFR flight plan for a two hour cross country flight. The procedures grade reflected his skill in obtaining and evaluating weather, plotting his course on a chart, and establishing check points and distances, estimated time enroute, headings, altitudes, weight and balance, and fuel requirements. Planning operations were to be completed in less than 30 minutes. The judgment and problem solving grade reflected demonstrated judgment in dealing with special problems created by weather, restricted areas, Notams, etc.

Aircraft Preflight

The preflight check was expected to be completed in accordance with the checklist provided in the aircraft. The subject was required to determine whether the aircraft was ready for flight and to know the appropriate remedial action for the correction of unsatisfactory items. No attempt was made to create discrepancies. Below average grades reflected failure to check or detect important items. Above average grades reflected careful checking or clever detection of obscure discrepancies.

Start, Taxi and Run-Up

This phase was also expected to be in accordance with the check-list provided in the aircraft. Specific items observed were clearing the propeller area before starting the engine, use of the controls to counter-act wind while taxiing at a safe speed, checking area for clearance prior to run-up and adherence to taxi clearance procedures.

Take-Off Departure

The motor coordination grade was based on the subjects' demonstrated take-off and climb out performance. The grade was based on an average of all the take-offs observed during the flight, but the initial take-off and climb-out was given the greatest weight. The procedural grade was based on adherence to procedures for departure from the traffic pattern and for take-off and climb of the aircraft as appropriate. A below average grade was assigned for any violation of established procedures.

Slow Flight and Stalls

Slow Flight was conducted at a speed such that 20° increase in pitch attitude caused a stall. In the Cessna 150 this is at a speed near 55 mph with the stall warning audible. Stalls were entered from approach, departure and accelerated flight conditions. The subject was expected to recognize and make a normal recovery from the stalls.

VOR Orientation and Tracking

The procedural grade was based on the subjects' ability to determine and tune the VOR to the desired station frequency, identify the station, and obtain the bearing to it. The judgment grade was based on the subject's ability to use the VOR to determine the aircraft's position and to solve simple navigation and tracking problems.

Simulated Engine-Out

The simulation of a failed engine was initiated by simultaneously retarding the throttle, adding carburetor heat and directing the subject to proceed as if the engine had failed. This was done at least once each flight when least expected. It was desirable that the simulated emergency be carried out completely to a touch down, but if this was not practicable the latter portion was simulated from the traffic pattern around an active runway. This simulation was seldom carried out completely to a landing. For all simulated engine failures the subject was expected to immediately establish a glide, pick his spot for landing and announce his plan. The grades reflect the performance averaged over all simulated emergencies given during the flight. The judgment grade refers to the choice of field, planning and approach, accounting for the wind, and evaluating the situation. The coordination grade refers to how well the subject handled the aircraft in a power off condition. Below average grades were given for actions which would have not resulted in a safe landing.

Simulated Loss of Horizon

This simulation was conducted during the cross-country flight at an unannounced time. An instrument hood was handed

to the subject and he was told to assume that he had inadvertently flown into clouds. He was expected to be able to make a 180° reversal on instruments and present a revised plan to cope with the situation. The subject was also expected to recover from the start of a power-on spiral and approach to a climbing stall while simulating instrument flight. This simulation was graded for all three skill categories.

Change in Flight Plan

This exercise required that the subject proceed to an alternate destination because of unexpected conditions which develop in flight and was the natural follow-on to having inadvertently run into clouds obstructing the route to the original destination. The procedures grade reflected the action taken to recalculate the flight planning and the procedures used to advise flight service of the change in destination.

Radio Procedures

The grade for procedural skill was based on the subjects' ability to determine and tune the correct frequencies, make the required calls and use the proper phraseology. The judgment grade was included because there is so often a problem to be solved in connection with radio usage. Typical examples are the interpretation of tower instructions, answering questions asked by the tower or flight service and knowing how to get required information by using the radio.

Landings

Grades were entered on every observed landing and the subject was always expected to attempt to land as close as possible to a previously designated point on the runway. Typically, the point was one of the runway centerline marks. Grades ranged from 0-5 as shown on the flight Evaluation Record Form (Figure 3) and were recorded for pattern and accuracy. The grades for accuracy were determined primarily by the location of the first point of touchdown relative to the aim point and were reduced if other characteristics of the landing were poor. There was also a grade for each landing pattern listed

as a judgment skill. This grade reflected the entry into the pattern, adherence to the traffic pattern altitude, maintenance of correct approach speeds and safe aircraft attitude. The first and last flights normally included 5 or 6 landings each. An attempt was made to make each landing different by asking for different flap settings. Comments were offered on the previous pattern and landing only after it was completed. A grade of zero was awarded if the approach or landing was so unsafe that the Evaluator had to take over control of the airplane.

For all flights grades were awarded on the following:

Aircraft Preflight
Start, Taxi, and Run-Up
Take-Off and Departure
Simulated Engine Out
Radio Procedures
Landings
Overall Grade

For the first and last flights additional grades were included on:

Slow Flight and Stalls
Landings (total of 5 or 6)

The cross-country flight included additional grades on:

Flight Planning and Filing
VOR Orientation and Tracking
Simulated Loss of Horizon
Change in Flight Plan
Landings (at several airports if feasible)

The subject was given comments on his performance, but no information on grades or the grading system.

Subject Selection

Subjects were selected for the flight testing program from the information submitted on the Pilots' History Questionnaire (Appendix A-2). Selection of the subjects was based on the distribution of the Sample Population as described by Figure 4.

SAMPLE POPULATION	RANGE	RATIO
Total Flight Time	<150:150-300:300-600:>600	1:1:1:1
Weeks Since Last Flight	<2:2-6:>6	1:1:1
Years Since Certification	<3:3-6:6-15:>15	1:1:1:1
Type Initial Training	FAA:Military:Other Approved School	2:1:1
Age	<30:30-37:38-45:>45	1:1:1:1
Gender	Male:Female	20:1
Pilot Category	Civil:Professional	12:1
Certificate Held	Private:Commercial	5:1

DISTRIBUTION BASED ON CURRENT KNOWLEDGE
OF TOTAL POPULATION

Figure 4.

A breakdown within the population selected is shown below:

Sample Population
(1000 subjects)

324 subjects responded
*28 not eligible

Flight Testing Selection Process
(296 subjects eligible)

Private Pilots	Commercial Pilots
(270 eligible)	(26 eligible)
Subjects Selected	Subjects selected
60 male	8 male
3 female	0 female (no applications)

Age Groups		Total Time Range	Years Since Certification (Range)
Under 30	29	70-380 hours	1-7 years
30-37	19	66-525 hours	1-12 years
38-45	13	67-500 hours	1-15 years
Over 45	10	75-5200 hours	2-15 years

*Eligibility Criteria:

1. Private or Commercial Pilot Certificate
2. Non-Instrument Rated
3. Current Medical Certificate
4. Resides within 50 miles of Hanscom Field.

Flight Operations Summary

Of the seventy-one subjects selected for flight testing, sixty-five were scheduled and completed at least one flight. Eight subjects subsequently dropped out of the program for personal reasons leaving a total of fifty seven who completed the three flights. The data for two of these subjects was considered incomplete and was not included in the data analysis. A Flight Operations Summary is shown in Figure 5. A copy of the printed introduction to the program (Appendix D-1) was given to the subject and an Experience Data Form (Appendix D-2) was completed prior to the first flight.

FLIGHT OPERATIONS SUMMARY

Flight No.	Flights Scheduled	Flights Cancelled Weather	Flights Cancelled Other	Flights Completed	Flight Hours
F1	110 Private				
	16 Commercial				
	126	45	16	65	83.4
F2	116 Private				
	40 Commercial				
	156	73	24	59	120.7
F3	74 Private				
	25 Commercial				
	99	30	12	57	79.6
Totals	381	148	52	181	283.7

Figure 5.

IV ANALYSIS

Data Reduction

The various measures of skill were analyzed for the effects of total and recent flight experience by computer, using a set of biostatistics programs (BMD Statistics Programs, Reference 4 and also Appendix F-1). Data was prepared casewise by flight, and punched onto 80 column cards. (The organization of these data cards is given in the Flight Evaluation Record Coding Sheet, shown in Appendix E.) Preparation of the Flight Evaluation Record cards from the individual flight evaluation record forms and the experience data involved some preprocessing of information. In particular, Total Time, Total Time in Type (Cessna 150), Recency, Landing Recency, Type Recency, and Type Landing Recency were calculated from the data available on the flight experience forms and evaluation records, using an interactive FOCAL language program shown in Appendix F-2. By preprocessing much of the individual pilot's flight history in this way, the total amount of data carried into the final analysis was reduced, and the data structure for the subsequent BMD analysis was considerably simplified. Normally the Flight Experience Data form was filled out by each subject just prior to the first evaluation flight. Care was taken to ascertain that records were kept of all subsequent non-MIT program flights ("interflights"), and that these data were entered into the recency calculations. In cases were there was doubt, subjects were contacted by mail again after completing the program, and asked for data on any possible interflights.

Effect of Parametric Experience Variables on Overall Grade

In order to assess the influence and relative importance of various parametric experience variables on the overall grade received by a subject on an individual flight, a stepwise regression analysis was performed (using the program BMD 02R). The program attempts to find a linear mathematical relationship between overall grade and the various experience factors by fitting the data with a multidimensional surface which is

optimal in a least mean squares sense. The stepwise approach is particularly useful in experiments such as this where the relative order of importance of the various experience factors is not known. Basically, the program operates as follows: It selects the single experience variable which best predicts overall grade. In a second step, the program finds the variable which best predicts the overall grade given that the effect of the first variable on overall grade has been removed. In the steps that follow, either: a) a variable is entered which best improves the prediction of skill given all the variables entered from the previous steps; or b) a variable is removed from the set of predictors if its predictive ability falls below a given level. The process is terminated when no further variable improves the prediction of overall grade.

More complete descriptions of the stepwise regression technique can be found in References 4 and 5. Included as experience factors were: Age, Years since Certification, Total Time, Total Time in Type, Overall Recency, Type Recency, Landing Recency, and Type Landing Recency. The program was run successively using several different transforms (such as logarithmic and exponential) of the Total Time and Recency parameters to determine the stepwise regression which accounted for the greatest amount of the variance in the overall data. The resulting regression which accounted for a total of 24.3% of the variance in the overall data, was based of the following model:

$$\text{Overall Grade} = K_o + K_1 \text{ (Cessna 150 Recency)} + K_2 \text{ (Log}_{10}\text{(total time))} + K_3\text{(years certificated)} + K_4 \text{ (Log}_{10}\text{(Cessna 150 time))} + K_5\text{(age)} + E_o$$

where E_o is an error variable representing the error incurred in approximating skill by the regression function.

REGRESSION COEFFICIENTS

Partial Regression Coefficient	Value	Std. Error of Regression Coefficient	% of Overall Variance accounted for
K_o	1.42		
K_1	.25	.09	9.5
K_2	.73	.16	7.4
K_3	- .030	.01	3.8
K_4	.15	.06	2.5
K_5	- .0088	.006	1.1
			24.3%

Table 1

The partial regression coefficient represents an estimate of the effect of the particular associated experience variable on overall grade when the other experience variables are held fixed. Due to the logarithmic transformation of total time variable, some of the coefficients are difficult to interpret directly. However, when the effects of the logarithmic transformations are taken into account, one can observe that averaging across the sample, pilots who have either:

1. .4 hrs/week more type recency, or
2. 32% more total time, or
3. 3.3 fewer years since certification, or
4. 150% more time in type

have, on the average, a 0.1 skill unit higher score.

The standard error of the regression coefficient gives a measure of the accuracy to which a particular coefficient is known. In particular, it is an estimate of the standard deviation of the distribution of the regression coefficient which would be obtained if the same analysis were performed on another set of similar flight data from the same population.

The individual components of the regression shown in Table 1 are plotted in Figures 6, 7, 8, 9, and 10. These figures describe the individual effects of Type Recency, Total Time, Years Since Certification, Time in Type and Age, on overall grade for the sample population, under the condition that all inde-

pendent variables other than the one being plotted remain constant. Figure 11 shows curves of constant skill as a function of Type Recency and Total Time. When interpreting these figures, however, it is important to keep in mind that the regression model is merely a description of the data obtained from the sampled pilots. Although the regression can be expected to predict the mean overall grade of the pilots in this study, it does not necessarily prove that the experience variables are causal in any sense, however attractive this hypothesis may seem. This is because there always remains the possibility that there exist parametric experience variables other than those considered in this study which exert a stronger influence on overall grade, and which happen to be correlated with the independent variables found by the regression analysis.

On the other hand, given the large number of different experience variables considered in this study, it is difficult to imagine what major experience factors were not considered. From the results of this study, one could assert that, for example, because pilots in our study with .4 hrs/week more Type Recency had, on the average, 0.1 skill unit higher performance, it seems reasonable that a pilot who increased his practise rate by that amount would experience a corresponding change in skill. Such a statement cannot be regarded as "proven" by the regression analysis however. This difficulty is, of course, inherent in the process of model-making using statistical techniques. In defense of the hypothesis that the regression parameters may be considered causal, it can be said that none of the significant effects found by the regression are unexpected, and therefore that there exist no particular grounds for rejecting the hypothesis that the regression variables are causal.

The analysis indicates that the five parametric experience variables can account for a total of 24.3% of the variance in this particular set of data. The individual partial regression coefficients are statistically nonzero. The probability that they are zero and the value found occured by chance is less than .1% for log of total time, .5% for years since certifica-

tion and type recency, 1% for log of total time in type, and 15% for age.

It should be observed that stepwise regressions based on untransformed variables or including transformations of other variables or with certain other variables witheld could account for 10-20% of the overall variance. The regression given previously, accounting for 24.3% of the variance, was the most successful attempted.

The finding that the measured experience factors account for only 25% of the overall grade indicates that other factors and interactions contribute significantly to pilot performance. One possibility, previously discussed, is that there exist important experience factors common to all pilots other than the subset considered in the analysis which could account for an additional component of the variance. More probable sources of the remaining variance are the three non-experience related groups of factors discussed in Section II (Theory).

Operational constraints in test program during the winter months prevented the use of a balanced design in which each subject flew with each of only three instructors. Hence, it was not possible to directly determine the component of overall variance due to instructors. It was observed that although all instructors gave a median grade of 3, the instructors were found to differ in a statistically distinguishable way. The effect of these differences, and "roundoff" error associated with the use of integer grades undoubtedly contributes to the overall variance.

It was, however, possible to assess the component of variance due to fixed (latent skill) effects associated with individual subjects. (Group 1 in Section II). The regression model previously described predicts the average skill of the sample population. The overall skill of an individual pilot may be considered as predicted by the regression model plus an additional constant term due to his own latent ability. Looking across the sample population, the additional constant term follows a distribution which has, necessarily, zero mean,

and an estimated standard deviation of .72. This was determined by an analysis of variance of the overall grades with the effects accounted for by the regression removed. (Examination of regression residuals in this way effectively constitutes an analysis of covariance.)

Fixed effects due to the 55 subjects in 165 flights was found to contribute 30% of the overall variance in all the data. Thus, the regression model taken together with a consideration of latent skill effects can account for over half the variance in the overall skill grades. Sources of the remaining 45% of the variance in the data include such factors as: effects due to instructors, "roundoff" error, and the individual pilot's flight to flight variability in performance.

Individual Skill Grades

A statistical summary of the parametric flight data variables is given in Table 2. This table was generated by the program BMD 01D. The mean is the average of the variables over all flights for which data was taken. The standard error of the mean is the standard deviation divided by the square root of the sample size. It estimates the standard deviation of the distribution of means one might obtain if the study was to be repeated many times. Thus, it is indicative of the confidence which can be placed in the listed means. The sample size is the number of flights on which the variable was recorded. The maximum value, minimum value, and range are self-explanatory.

Several observations can be made from this table:

The Mean Age, Total Time, and Years Certificated compare well with the values known for the total population.

The Landing Recency divided by the mean Recency (both overall and for Type) gives an approximate landing rate of two landings per flight hour.

The average quiz score was 7/10.

An interesting observation can be made by considering the individual skill grades (landings excluded). The four highest and four lowest scores are shown in Figure 12. Of interest is

VARIABLE	VAR.NO.	MEAN	S.D.	S.E. OF MEAN	SAMPLE	MAXIMUM	MINIMUM	RANGE
Years Certificated	1	6.1666	5.8438	0.4430	174	26.0000	1.0000	25.0000
Age	2	36.8902	10.0791	0.7641	174	60.0000	20.0000	40.0000
Total Time	3	341.9551	762.4392	57.8004	174	5916.0000	47.0000	5869.0000
C-150 Time	4	52.5122	66.3800	5.0614	172	381.0999	0.1000	380.9998
Recency	5	0.8524	1.1810	0.0895	174	7.6600	0.0	7.6600
Landing Recency	6	1.7869	2.8476	0.2159	174	23.7800	0.0	23.7800
C-150 Recency	7	0.2921	0.6065	0.0460	174	3.6700	0.0	3.6700
C-150 Landing Recency	8	0.5623	0.9202	0.0700	173	7.5400	0.0	7.5400
Quiz Score	9	6.6309	2.1159	0.2309	84	10.0000	2.0000	8.0000
Overall Grade	10	2.8563	0.7426	0.0563	174	4.0000	1.0000	3.0000
Flight Planning R	11	3.0500	0.9099	0.1175	60	5.0000	0.0	5.0000
Flight Planning P	12	3.1667	0.8471	0.1094	60	5.0000	0.0	5.0000
Preflight	13	3.2631	0.7403	0.0566	171	5.0000	1.0000	4.0000
Taxi	14	3.0689	0.5946	0.0451	174	5.0000	1.0000	4.0000
Take-Off R	15	3.0574	0.6860	0.0520	174	5.0000	1.0000	4.0000
Take-Off M	16	3.0982	0.7287	0.0554	173	5.0000	1.0000	4.0000
Slow Flight	17	3.0531	0.7176	0.0675	113	5.0000	1.0000	4.0000
Stalls R	18	2.7396	0.6025	0.0615	96	4.0000	1.0000	3.0000
Stalls M	19	2.8437	0.7008	0.0715	96	4.0000	1.0000	3.0000
VOR R	20	3.0183	0.8387	0.0803	109	5.0000	0.0	5.0000
VOR P	21	3.0275	0.7753	0.0743	109	4.0000	0.0	4.0000
Engine Out P	22	3.0000	0.8165	0.0716	130	5.0000	1.0000	4.0000
Engine Out M	23	3.0154	0.8351	0.0732	130	5.0000	0.0	5.0000
Loss of Horizon R	24	2.9231	0.9042	0.1254	52	5.0000	0.0	5.0000
Loss of Horizon P	25	3.0000	0.8856	0.1228	52	5.0000	0.0	5.0000
Loss of Horizon M	26	2.8654	0.9294	0.1289	52	5.0000	0.0	5.0000
Pilotage & D.R. R	27	2.9701	0.7582	0.0926	67	4.0000	1.0000	3.0000
Pilotage & D.R. P	28	3.0000	0.8165	0.0998	67	4.0000	1.0000	3.0000
Change in F.P. R	29	3.0000	0.6213	0.0816	58	4.0000	1.0000	3.0000
Change in F.P. P	30	3.0517	0.6602	0.0867	58	4.0000	1.0000	3.0000
Radio Procedure R	31	3.0059	0.8762	0.0674	169	5.0000	0.0	5.0000
Radio Procedure P	32	3.0651	0.7954	0.0612	169	5.0000	0.0	5.0000
Landing #1 Pattern	33	2.8161	0.8538	0.0647	174	5.0000	0.0	5.0000
Landing #1 Accuracy	34	2.7816	1.2806	0.0971	174	5.0000	0.0	5.0000
Landing #2 Pattern	35	2.8758	0.8240	0.0684	145	5.0000	0.0	5.0000
Landing #2 Accuracy	36	2.8689	1.3031	0.1082	145	5.0000	0.0	5.0000
Landing #3 Pattern	37	3.0000	0.8099	0.0722	126	5.0000	0.0	5.0000
Landing #3 Accuracy	38	3.1666	1.2946	0.1153	126	5.0000	0.0	5.0000
Landing #4 Pattern	39	3.0532	0.8471	0.0874	94	5.0000	1.0000	4.0000
Landing #4 Accuracy	40	3.2659	1.3374	0.1379	94	5.0000	0.0	5.0000
Landing #5 Pattern	41	3.1389	0.7563	0.0891	72	5.0000	1.0000	4.0000
Landing #5 Accuracy	42	3.4583	1.2326	0.1453	72	5.0000	0.0	5.0000
Landing #6 Pattern	43	3.1087	0.7372	0.1087	46	5.0000	2.0000	3.0000
Landing #6 Accuracy	44	3.5435	1.1097	0.1636	46	5.0000	0.0	5.0000
Log Total Time	45	2.3198	0.3374	0.0256	174	3.7720	1.6721	2.0999
Log C-150 Time	46	1.2115	0.9178	0.0700	172	2.5810	-1.0000	3.5810

R = Procedure Retention and Recall   P = Judgment and Problem Solving   M = Motor Coordination

STATISTICAL SUMMARY OF PARAMETRIC VARIABLES

Table 2.

the observation that the poorest average scores are on stalls and flight by instruments. The Evaluators reported that many of the subjects had not done stalls since their initial flight training. Some subjects had no simulated instrument experience at all. On the other hand, the above average skills appear to be ones which are practiced fairly often.

As a check on the hypothesis that the overall grade was a "mental" average by the Evaluator of the subjects' individual skill scores, the mean of all these scores taken together was calculated. Its value was 3.05 compared to 2.86 for the actual overall grade mean. Similar means were calculated for skill categories defined as recall, problem solving ability, and motor skills. The means here were 3.06, 3.07, and 3.02 respectively.

Correlations

A number of the individual skill scores were also found to be correlated with the overall grade using the program BMD 03D. The correlation coefficient, ρ, is an indicator of the strength of linear association of two variables. The correlation coefficient, ρ is defined by

$$\rho \triangleq \frac{S_{ij}}{S_i S_j}$$

where

$$S_{ij} \triangleq \frac{1}{N-1} \sum_{k=1}^{N} (X_{ik} - \overline{X}_i)(X_{jk} - \overline{X}_j)$$

This equation represents the sum of the product of the deviation of X_i and X_j from their respective means. By definition this is the covariance of X_i and X_j.

$$S_i^2 = \frac{1}{N-1} \sum_{j=1}^{N} (X_{ij} - \overline{X}_i)^2$$

This equation represents the sum of the squares of the deviations of X_i from its mean. This by definition is the variance of X_i or the square of the standard deviation of X_i. The correlation coefficient is thus the ratio of the covariance to the product of the two standard deviations. By definition $|\rho| \leq 1$, with $\rho = \pm 1$ representing an exact linear dependence of the two

variables (i.e., variables X_1 and X_2 could be explained exactly by an equation of the form $X_2 = mX_1 + b$ where m and b are constants). A positive sign for ρ indicates a change in one of the variables results in a corresponding change (i.e., both increase or decrease simultaneously) in the other. On the other hand, a negative sign for ρ indicates the variables change simultaneously but in opposite directions. The closer ρ is to 1 the greater the linear association between the two variables.

The variables for which the correlation coefficient indicated some linear dependence are given below. Overall grade correlated with:

Flight Planning, $\rho = .7$
Stall (motor skills), $\rho = .6$
Take-Off, $\rho = .6$
VOR, $\rho = .6$
Pilotage and Dead Reckoning, $\rho = .6$
Change in Flight Plan, $\rho = .6$
Radio Skills, $\rho = .6$

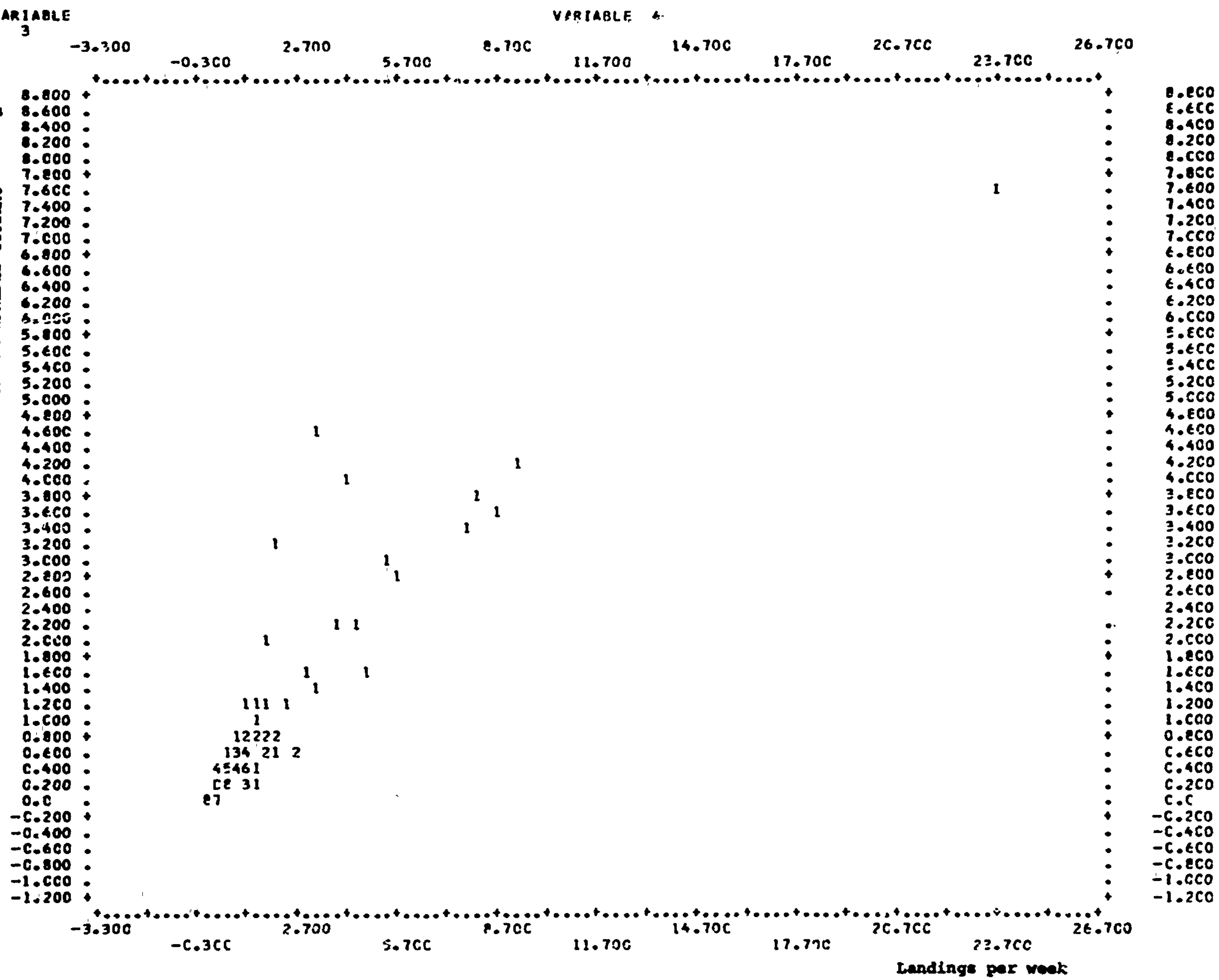
These correlations suggest that overall grade varies in a linear fashion with the individual skill scores indicated, further supporting the hypothesis that the overall grade is a composite of these scores.

Other correlations of interest were:

Overall Recency and Landing Recency, $\rho = .89$
Type Recency and Type Total Time, $\rho = .7$
Type Recency and Type Landing Recency, $\rho = .9$

The correlations between Recency and Landing Recency both overall and in Type agree with intuition. The correlation between Type Recency and Type Total Time may indicate that pilots fly often in the same type aircraft, a not unreasonable assumption.

It must be pointed out that the correlation coefficient by itself may not always be simple to interpret, especially when it is below 0.7. Above this value however, on can expect to see a reasonably linear relationship between the two variables if they are plotted. An example of such a plot for Overall



OVERALL RECENCY VS. OVERALL LANDING RECENCY

Figure 13.

Recency vs. Overall Landing Recency is shown in Figure 13. As mentioned above, the correlation coefficient here is approximately 0.9 and the plot is indeed nearly a straight line.

Examination of Non-Parametric Data

Correlation coefficients can not be defined on the non-parametric data in the study such as Evaluators, type of operation, and airfield type. Relationships between these parameters and certain of the parametric variables were examined using the Chi-squared analysis of contingency tables technique (Reference 5, p. 77ff). A computer program, CONTAB, was written in the interactive language, FOCAL, to perform such analyses. A copy of this program is included in Appendix F-3.

Those relationships of interest in which some dependence of parameters was found are as follows:

Airfield Type and Radio Skills, $p < 0.001$ (the probability, p, that this dependence occurs by chance is < 0.1%)

Radio scores were higher for pilots regularly flying from controlled airfields.

Airfield Type and Overall Grades, $p < 0.05$

Overall grade was higher for pilots regularly flying from controlled airfields.

Relationships of some interest for which no dependence of parameters could be demonstrated were:

Training Type and Overall Grade
Operation Type and Overall Grade
Airfield Type and Landing Skills
Overall Grade and Written Quiz Score

The mean landing pattern scores and the mean landing accuracy scores are plotted in Figures 14 and 15. It is interesting to note the slow but steady improvement. Note that the increase is small relative to the magnitude of the sample standard deviation. There appears to be an effect on the average although it is difficult to observe the effect when looking at only a few landings of a single pilot. However, it would not be correct to assume that actual overall landing skill in a non-test situation increases in exactly this way with

practice, because in this study, repeated landings were normally made on the same runway. It is reasonable to expect that the pilot adjusts to that particular landing pattern and touchdown point. The landing skill scores would probably not increase as rapidly if landings were made consecutively to different airports.

V CONCLUSIONS

This work has been a study of the observed skills of a sample of non-instrument rated, private and commercial pilots. The test sample consisted of 55 subjects who flew three flights with an evaluator in a Cessna 150. The sample appeared representative of the population in terms of such factors as age and experience. Several experience factors were found which showed correlation with the observed piloting skill of the sample. In order to make these correlations it has been necessary to look at the skills of the sample population as a whole. It was not possible to perturb the experience factors of an individual pilot enough to see the effect on his individual overall skill. Consequently, it has not been proven that one can cause individual skill changes by changing experience factors. That is an assumption which is encouraged by the fact that the population shows these characteristics. In explaining the conclusions it is implied that these statistics about the population can be applied to an individual. The reader should be aware that the study only described the characteristics of the sample population and that interpretations on individuals requires a postulate which was not proven. What is meant in talking about "a pilot" means what would happen on the average to the total population under the assumption that experience changes would cause skill changes, in the same way in which they varied over the sample. Keeping this subtle distinction in mind, the following major conclusions are drawn from the results:

1. Experience factors account for only about 25% of the variance in observed skill. Effects due to the latent skill of each individual subject account for about 30%. It is therefore probably necessary to fly with an individual pilot in order to accurately measure his skill. This large variation between individuals makes prediction of an individual pilot's skill based only on experience factors unreliable. However, effects due to skill may be observed when looking across a population of pilots.

2. The most important experience factor for maintaining skill is recent flight experience as measured by Recency which is approximately the average rate at which the skill is practiced. Recency predicts the largest percentage of the variance in skill grades due to experience factors and is the single experience factor over which the pilot has immediate control.

3. Another important factor showing correlation in a regression model for skill involved the logarithm of total time. The log dependence comes from the apparent fact that skill increases with total time at a rate that is inversely proportional to the total time accumulated.

4. From a statistical viewpoint, the increase of skill with the log of total time is offset by a linear decrease of skill with years since certification. In the regression model after a large number of total hours builds up, the linear decrease of skill due to years since certification overpowers the logarithmic increase due to total time. The hypothetical effect is shown graphically in Figure 16 for a pilot who consistently flys 100 hours a year. If the effect due to years since certification is causal, the trend could be countered by qualifying for a new certificate or flying at a greater rate. However, this interpretation should only be accepted cautiously. The effect can also be attributed exclusively to the fact that the regression only describes pilots from the sample population without advanced ratings. Pilots still in this population after many years may not be typical of the overall population of all pilots. More probably both effects are at work simulatenously

5. There was no significant relationship between the score on written quizzes and overall grade. Neither did the subject's own assessment of his own skill show significant relationship with overall grade. There was no significant relationship found between skill and geographic factors. There was no significant relationship between skill and type of initial training.

6. Individual skills receiving the highest grades on the average were those probably most often practiced such as flight

planning, preflight, taxi and take off. Those skills receiving the lowest average grades involved stalls and simulated instruments flight. Most of the subjects had practiced these skills little or never since their initial training. It is interesting that inadvertent stalls and flight into instrument weather contribute to a major percentage of the accidents to pilots in the population according to NTSB accident statistics.

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
Measurement Systems Laboratory
Bldg. N52-395
Cambridge, Massachusetts 02139

Dear Sir:

The Massachusetts Institute of Technology is conducting an investigation to learn more about the flying skills of private and commercial pilots in the U.S., how these skills vary with recent and total pilot experience and the extent to which pilot skills degrade when not exercised.

If your response to the enclosed questionnaire indicates that your total flying experience is in some way typical of the pilot population, (regardless of recent flight experience) you are welcome to participate in this research program.

If you are selected as a candidate for this research program, you will be given -at no cost to you- at least two flights and possibly as many as five flights with a Certified Flight Instructor at an airfield near your home. You will do all the flying and will be asked to perform only those maneuvers with which you are familiar. Sufficient latitude in time will be available during these flights to permit instruction where appropriate.

We think you will enjoy this experience and we hope that we can register you as a volunteer to receive this free flight time. If you are interested in participating, please complete and return the questionnaire as soon as possible. Should you choose not to participate, by filling out and returning the questionnaire you can help assure the statistical validity of the investigation.

Respectfully,

Walter M. Hollister.

WMH/m
Enclosure

Appendix A-1

PILOTS HISTORY QUENSTIONNAIRE

NAME ______________________________ DATE OF BIRTH ____________

Last First Middle Mo. Day Year

Address ____

Street City State Zip

Home Telephone ____________ Business Telephone ____________

---

1. Pilot Certificate: Issue Date ____________

   Commercial ☐ Month Year

   Private ☐

Ratings and Limitations: ____________________________________

2. Medical Certificate:

   Class: ____________ Its is current: ____________

3. Source of Initial Flight Training (Military, Civilian Flight School, etc.)

Certificate	Source	Model Aircraft	Dates Attended
Commercial	______	____________	____________
Private	______	____________	____________

Remarks: List other flight training completed and pilot qualifications not included in current FAA certification and ratings:

____

____

List all single engine aircraft models in which you have qualified: ____

____

4. Flight Time Summary:

   a. Past 3 Months

Model Aircraft	______	______	______	______
Flight Time (Hr.)	______	______	______	______
Cross Country (Hr.)	______	______	______	______
Night Time (Hrs.)	______	______	______	______
No. of Landings	______	______	______	______

   b. Total Flight Time During Past Year ____________

   c. Total All Flight Time ____________

5. Have you flown regularly for hire? ____________

6. Do you keep a current pilots Log Book? ____________

7. How do you evaluate your present pilot skill level relative to your skill at the time you were last certificated?

   Same ____________ Better ____________ Not so good ____________

Appendix A-2

8. Assume that you were flying regularly at the rate of 1 hour per week and that you stopped all flying for a period of 6 months. How many flight hours would you estimate you would need to regain your former pilot proficiency? ______Hours.

9. Can you participate in the flight test portion of this program?___________

10. If selected as a candidate, on what days would you be available for flight testing?

Mon.____ Tues. ____ Wend. ____ Thurs. ____ Fri. ____

Sat. ____ Sun. ____

I am not available during the following period:_____________

Appendix A-2

MATHEMATICAL DEFINITION OF RECENCY

Recency is defined as the current rate at which a skill is being practiced. The problem is that the value of the current rate has to be averaged over a suitable time interval. This averaging interval is intimately associated with the degradation of skill with time under two simple assumptions: 1) the Recency increases at a rate in direct proportion to the time spent practicing; and 2) the percentage decrease in Recency with time is proportional to the time spent without practice.

S = demonstrable skill at time t as scored by a competent evaluator

H = total number of hours (or repetition) of practice of the skill

R = Recency

After practice

$$\Delta R = A\Delta H \tag{1}$$

and without practice

$$\frac{\Delta R}{R} = - B\Delta t \tag{2}$$

With regular practice under steady state conditions the two increments, ΔR, must be equal. By definition, the value of steady state R is $\Delta H/\Delta t$. Then the two constants of proportionality (A and B) are equal, and they have the units of reciprocal time. Now let

τ = characteristic degradation time and set

$$\tau = \frac{1}{A} = \frac{1}{B}$$

Equations (1) and (2) may be combined to form an expression for the total ΔR, and this expression can be passed to the limit as Δt approaches zero to obtain

$$\tau\dot{R} + R = \dot{H} \tag{3}$$

Equation (3) or the approximations (1) and (2) can be used to determine the current value of Recency for any pilot once τ

Appendix B

is known. Conversely a characteristic skill degradation time for the pilot can be obtained by observing how his performance improves or degrades with or without practice. The variation of skill with Recency is a function that might be characterized as in Figure 17.

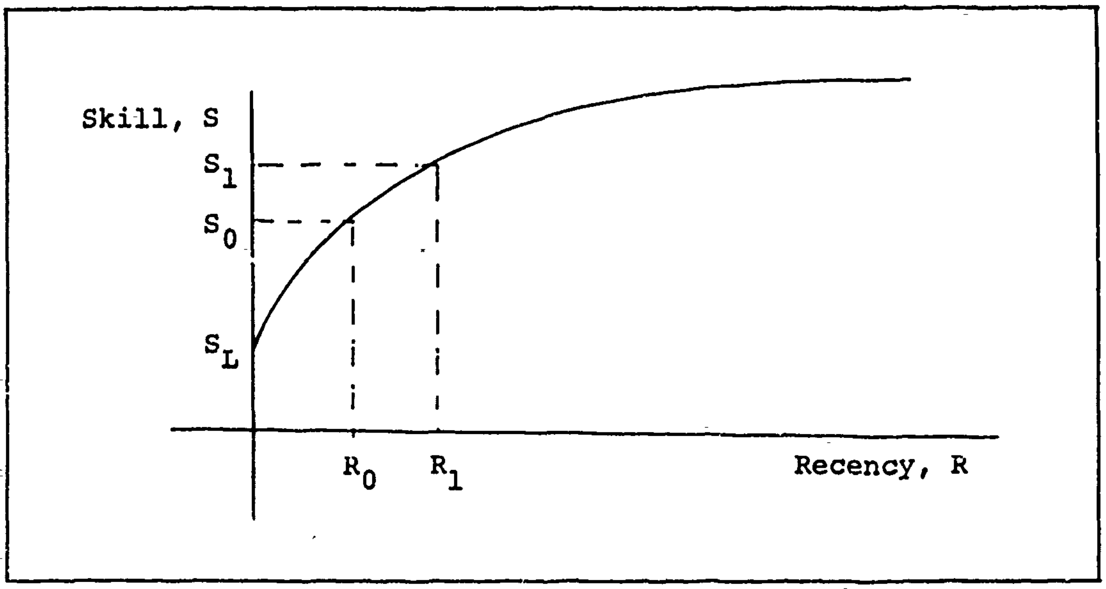


Figure 17. Variation of Skill with Practice Rate (Recency).

This figure shows S_L as the latent skill level without benefit of practice, S_o as a minimum acceptable skill level, and R_o as the corresponding Recency required to maintain that minimum skill level. For any pilot the change in S from S_o to S_1 can be expressed through a Taylor Series Expansion around the point (R_o, S_o) as

$$S_1 - S_o = K(R_1 - R_o) + \text{higher order terms} \qquad (4)$$

Under the assumption that the rate of accumulation of flying hours for the pilot is available from his log book and given three measures of skill at three different times, it is theoretically possible to determine for every pilot that is evaluated:

a) τ, Recency time constant characteristic degradation time;

b) K, the rate of change of skill with respect to Recency;

c) R_o, the minimum Recency required to maintain a minimum acceptable skill level.

Quiz-Flight #1

1) An aircraft may stall:

(a) only when in a nose-high attitude to the horizon.
(b) only when at low airspeeds.
(c) at any airspeed and in any attitude.
(d) only when both (a) and (b) are true.

2) Previous clearance must be received from using or controlling agency before flying into:

(a) a Warning, Restricted of Prohibited Zone.
(b) only a Restricted or Prohibited Zone.
(c) only a Prohibited Zone.
(d) only a Restricted Zone.

3) According to the F.A.R.'s, when flying a magnetic course between 0° and 179° inclusive at 3,000 feet or more above the surface, the aircraft shall be flown at:

(a) even thousands feet altitude aboven the surface.
(b) odd thousands feet altitude above the surface
(c) even thousands + 500 feet altitude above the surface.
(d) odd thousands + 500 feet altitude above the surface.

4) Carburetor ice forms:

(a) only when the air temperature is below 32°F and the humidity is high.
(b) especially readily in a 20°-70°F temperature range with high humidity.
(c) only when there is condensation in the air such as fog, rain, snow or sleet.
(d) only when the engine is throttled back and the humidity is high.

5) A pilot has his VOR omni bearing selector set on 280°, his course deviation needle centered and his to/from indicator reading "to" for a certain VOR station. From this infor-

Appendix C-1

mation one can assume that:

(a) he is on the 280° radial and has a magnetic heading of 280°.

(b) he is on the 100° radial.

(c) he is on the 100° radial with a magnetic heading of 280°.

(d) he is on the 280° radial with a magnetic heading of 100°.

6) The effective power output of an aircraft reciprocating engine will:

(a) decrease with higher temperature and humidity.

(b) increase with higher temperature and humidity.

(c) remain the same for all temperatures and humidities.

(d) increase with higher humidity and decrease with higher temperature.

7) The VFR weather minimums in a control zone are 500' vertically under, 1,000' vertically over, 2,000' horizontally from clouds and:

(a) a ceiling of 1,000 feet and 3 miles visibility.

(b) a ceiling of 1,000 feet and 1 mile visibility.

(c) a ceiling of 2,000 feet and 3 miles visibility.

(d) a ceiling of 2,000 feet and 1 mile visibility.

8) The special VFR minimums for a control zone which go into effect after an appropriate ATC clearance is received are:

(a) 3 miles visibility, 1.000 feet ceiling.

(b) 1 mile visibility, clear of clouds.

(c) 3 miles visibility, clear of clouds.

(d) 1 mile visibility, 1,000 feet ceiling.

9) If two aircraft are approaching each other at approximately the same altitude on an apparent collision course, one aircraft gives way to the other if the other aircraft:

(a) is larger.

(b) is slower.

(c) is approaching from the left.

(d) is approaching from the right.

10) Over congested areas the minimum clearance of the highest obstacles must be:

(a) 500 feet above, 2,000 feet horizontal.

(b) 500 feet above, 1,000 feet horizontal.

√(c) 1,000 feet above, 2,000 feet horizontal.

(d) 1,500 feet above, 2,000 feet horizontal.

Quiz-Flight #2

1) The maximum terrain elevation numbers on a sectional chart indicate:

   (a) the highest terrain in the area.
   (b) the highest terrain and/or man made obstructions in the area.
   (c) the highest man made obstructions only when they are higher than the terrain in the area.
   (d) none of the above.

2) All radio navigation aids on sectional charts are laid out in relation to:

   (a) the true north line.
   (b) the magnetic north line.
   (c) the longitude lines.
   (d) none of the above.

3) On a sectional chart the shaded-in airport symbol denotes:

   (a) airports with a control tower or a FSS.
   (b) airports with service facilities.
   (c) airports with hard-surfaced runways of at least 1500'.
   (d) restricted airports.

4) Magnetic heading plus or minus Deviation equals:

   (a) compass heading.
   (b) magnetic course.
   (c) true heading.
   (d) true course.

5) Winds aloft forecasts are given in:

   (a) kilometers per hour.
   (b) miles per hour.
   (c) knots per hour.
   (d) knots.

Appendix C-2

6) With regard to completion of flight plans, it is true that:

(a) At airports with control towers the tower will automatically close flight plans only if it is the airport of destination specified in the flight plan.
(b) The arrival notice must be filed by the pilot within an hour after arrival on a standard form provided for the purpose.
(c) The pilot should request the FSS to close the flight plan.
(d) At all airports with a control tower the tower automatically will close flight plans as soon as the landing is complete.

7) If an aircraft enroute on a cross-country flight passes within five miles of a tower-controlled airport its minimum altitude should be:

(a) 2,000 feet ASL.
(b) 2,000 feet AGL.
(c) 3,000 feet ASL.
(d) 3,000 feet AGL.

8) On aircraft equipped with fixed-pitch propellers the indication of carburetor icing would likely be:

(a) a decrease in engine RPM.
(b) engine roughness only.
(c) a loss of power only.
(d) any of the above.

9) The scale of sectional aeronautical charts is:

(a) 1:250,000.
(b) 1:500,000.
(c) 1:1,000,000.
(d) 1:1,500,000.

10) The most important reason for servicing fuel tanks to full capacity upon completion of a flight is because this procedure:

(a) prevents drying and cracking of the fuel cell inner liner which occurs when it is exposed to the air.
(b) minimizes the possibility of corrosion and structural damage due to moisture forming on and dripping from the outer walls of fuel tanks.
(c) prevents the fuel evaporation which occurs in partially-filled tanks.
(d) minimizes the possibility of fuel contamination from condensation of water on inner walls of partially-filled tanks.

INTRODUCTION TO THE PILOTING SKILLS RESEARCH PROGRAM

The purpose of this program is to obtain data which will indicate how experience factors influence observed piloting skill.

The scope of the program involves flights with approximately 100 private and commercial pilots who are neither instrument nor multi-engine rated. The plan is to obtain data on experience factors and observe the flying skills of each subject. These data will be processed by a computer program which will look for statistical correlations between observed skills and experience factors.

A typical program consists of the following steps:

1. Take data on your experience with the aid of your log book.
2. Ten question quiz.
3. Basic piloting flight.
4. Cross-country flight.
5. Idle period of 3-4 weeks.
6. A repeat of the first flight.

During the 3-4 week idle period, it would be appreciated if you did not fly. If you should fly during that period, we would like the information on flight time, landings, etc. from your log book.

During the flights, you should do things the way you feel they should be done. The experimenter will be pilot in command, but will act as observer pilot. At the end of the flight, he will comment on his observations. However, his remarks and your test results will be completely confidential: You as a subject are identified in the data only as a number. Our only record of names vs. numbers will be destroyed after the project is completed. The number code used will be changed during the processing of the data so that no one (including yourself) will be able to associate the data with a particular individual.

The aircraft you will be flying is a late model Cessna 150, maintained on a 100 hour inspection schedule. The aircraft is covered by property damage and liability insurance.

Appendix D

You are, of course, completely free to discontinue your participation in this study at any time, should you desire to do so.

If you have, at any time, further questions about the program, please do not hesitate to ask.

Subjects: (Please sign)

I hereby consent to take part in the piloting skills research program.

____

Appendix D

EXPERIENCE DATA

SUBJECT NO._____

DATE PRIVATE ________
MO YR

DATE OF BIRTH______

SEX __M __F

DATE COMMERCIAL ________
MO YR

TYPE INITIAL TRAINING

____FAA APPROVED SCHOOL

____MILITARY

____OTHER

PROFESSIONAL PILOT

____ YES

____ NO

LOCAL TERRAIN

____MTS

____FLAT

____COASTAL

AIR TRAFFIC DENSITY

____HIGH DENSITY

____LOW DENSITY

MAJORITY OF OPERATIONS _____TOWER CONTROLLED FIELD

_____UNCONTROLLED FIELD

LAST 10 FLIGHTS IN 1972

Julian Date	Flight Duration (HRS.)	No. Landings	if C-150
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Appendix D

EXPERIENCE DATA CONT.

SUBJECT NO. ____

DATA JUST PRIOR TO LAST FLIGHT SHOWN ABOVE:

TOTAL TIME (HRS.)______

TOTAL LANDINGS (NO)_____

C-150 TIME (HRS) ______

C-150 LANDINGS (NO)_____

RECENCY (HRS/WK) _____

LANDING RECENCY (NO./WK)____

C-150 RECENCY (HRS/WK)_____

C-150 LANDING RECENCY (NO/WK) ______

OWN ESTIMATE OF RECENCY TIME CONSTANT

(WKS)_____

OWN ESTIMATE OF SKILL RELATIVE TO WHEN CERTIFICATED:

IMPROVED ______

SAME _______

DETERIORATED _____

Appendix D

FLIGHT EVALUATION RECORD CODING SHEET

Card Column	Item
1-3	Subject Identification Number

From Experience Data Form: 7 or 77 missing data

Card Column	Item
4	Pilot Certificate: 1 = Private 3 = Commercial
5-6	Year of Issuance
7-8	Month of Issuance
9-10	Year of Birth
11	Gender 1 = Male 2 = Female
12	Type Training 1 = FAA Approved School 2 = Military 3 = Other
13	Professional Pilot 1 = yes 2 = no
14	Operations: 1 = coastal, high density 2 = coastal, low density 3 = flat, high density 4 = flat, low density 5 = mts, high density 6 = mts, low density 7 = unknown
15	Field Type: 1 = controlled 2 = uncontrolled

Data From Recency Program

cc 16	Flight Number 1 = F1 2 = F2 3 = F3
17-19	Julian Date
20-23	Total Time (prior to this flight, whole hrs)
24-27	Total Cessna 150 Time
28-31	Recency (xx.xx hrs/wk)
32-35	Landing Recency (xx.xx lndgs/wk)
36-38	C-150 Recency (x.xx hrs/wk)
39-41	C-150 Lndg Recency (x.xx lndgs/wk)

Data From Flight Evaluation Record: (7 = missing data

42	Instructor Code: 1-6
43-44	Quiz Grade
45	Overall Grade (round all grades away from 3)
46-47	Flight Planning
48	A/C Preflight
49	Start, Taxi, Runup

Appendix E

50-51	Take-off and Departure
52	Slow Flight
53-54	Stalls
55-56	VOR Orientation and Tracking
57-58	Simulated Engine Out
59-61	Simulated Loss of Horizon
62-63	Pilotage and Dead Reckoning
cc 64-65	Change in Flight Plan
66-67	Radio Procedures
68	Number of Landings on this Test Flight on which grades were given
69-70	1
71-72	2
73-74	3
75-76	4
77-78	5
79-80	6

Appendix E

Program	Description
01D	Means, Standard Deviations, Standard Errors, Sample Sizes, Ranges
02D	2-way Data Plots
03D	Correlations
05D	Histograms
08D	Cross Tabulations-Parametric vs. Non-Parametric Data
02R	Stepwise Linear Regression
03R	Multiple Regression
01V	One-way Analysis of Variance
07M	Stepwise Discriminant Function Analysis

BMD Programs (Ref.: BMD-Biomedical Computer Programs, W.J. Dizon, ed., Univ. of California Press, Berkeley, 1970).

Appendix F-1

PILOT8 RECENCY PROGRAM

```
WRITE ALL
C-FOCAL,1969

01.09 ERASE
01.10 A "SUBJECT #",SN,!,"-------------",!,!,"TOTAL TIME      ",H,!
01.30 A "C-150 TIME      ",CH,!
01.50 A "RECENCY         ",R4,!
01.70 A "LNDG RECENCY    ",RL,!,"C-150 RECENCY   ",CR,!
01.90 A "C-150 LNDG REC.",RC,!,!,"# FLTS IN '72",N,!
01.92 S K=N;S M=0.
01.93 I (K) 1.94,2.1,1.94
01.94 T !,"FLIGHT",%2.00,K
01.95 G 5.01

02.10 S M=1.
02.30 T !,!,!,"TEST FLIGHT",%2.00,M,!,"                          "
02.40 D 5.0
02.50 T !,"TOTAL TIME           ",%5.00,H,!
02.60 T "TOTAL C-150 TIME  ",CH,!
02.70 T "RECENCY               ",%5.02,R4,!,"LANDING RECENCY    ",RL,!
02.80 T "C-150 RECENCY       ",CR,!,"C-150 LNDG RECENCY",RC,!,!
02.81 I (M-3.) 2.82,8.1,8.1
02.82 A "# OF INTERFLIGHTS",P,!
02.83 S R=1.
02.85 I (P-R) 2.87,2.90,2.90
02.87 S M=M+1.;S R=0.;G 2.3
02.90 T !,"INTERFLIGHT #",%2.00,R,!,"                          "
02.91 D 5.0
02.93 S R=R+1.
02.95 G 2.85

05.01 A "    DATE",DF,"    DUR",HF,"    # LNDGS",LF
05.02 I (M) 5.03,5.06,5.03
05.03 I (R) 5.06,5.12,5.06
05.06 A "C-150?",RE
05.08 I (RE-0Y) 5.10,5.12,5.10
05.10 S QC=0.;S QL=0.;G 5.16
05.12 S QC=HF;S QL=LF
05.16 I (N-K) 5.22,5.42,5.22
05.22 S E=((DF-D)/28);D 7.1
05.23 I (DF-D) 8.2,5.24,5.24
05.24 S H=H+DH;S CH=CH+DC
05.32 S R4=(R4+.25*DH)*DT
05.34 S RL=(RL+.25*DL)*DT
05.38 S CR=(CR+.25*DC)*DT;S RC=(RC+.25*NC)*DT
05.42 S DH=HF;S DL=LF;S DC=QC;S NC=QL;S D=DF
05.44 S K=K-1.

06.20 G 1.93

07.10 S DT=1/(1+E+((E^2)/2)+((E^3)/6)+((E^4)/24)+((E^5)/120))

08.10 T !,!,!,!,?;QUIT
08.20 T !,"SEQUENCE OF FLIGHTS ENTERED REVERSED;BEGIN AGAIN";Q
*
```

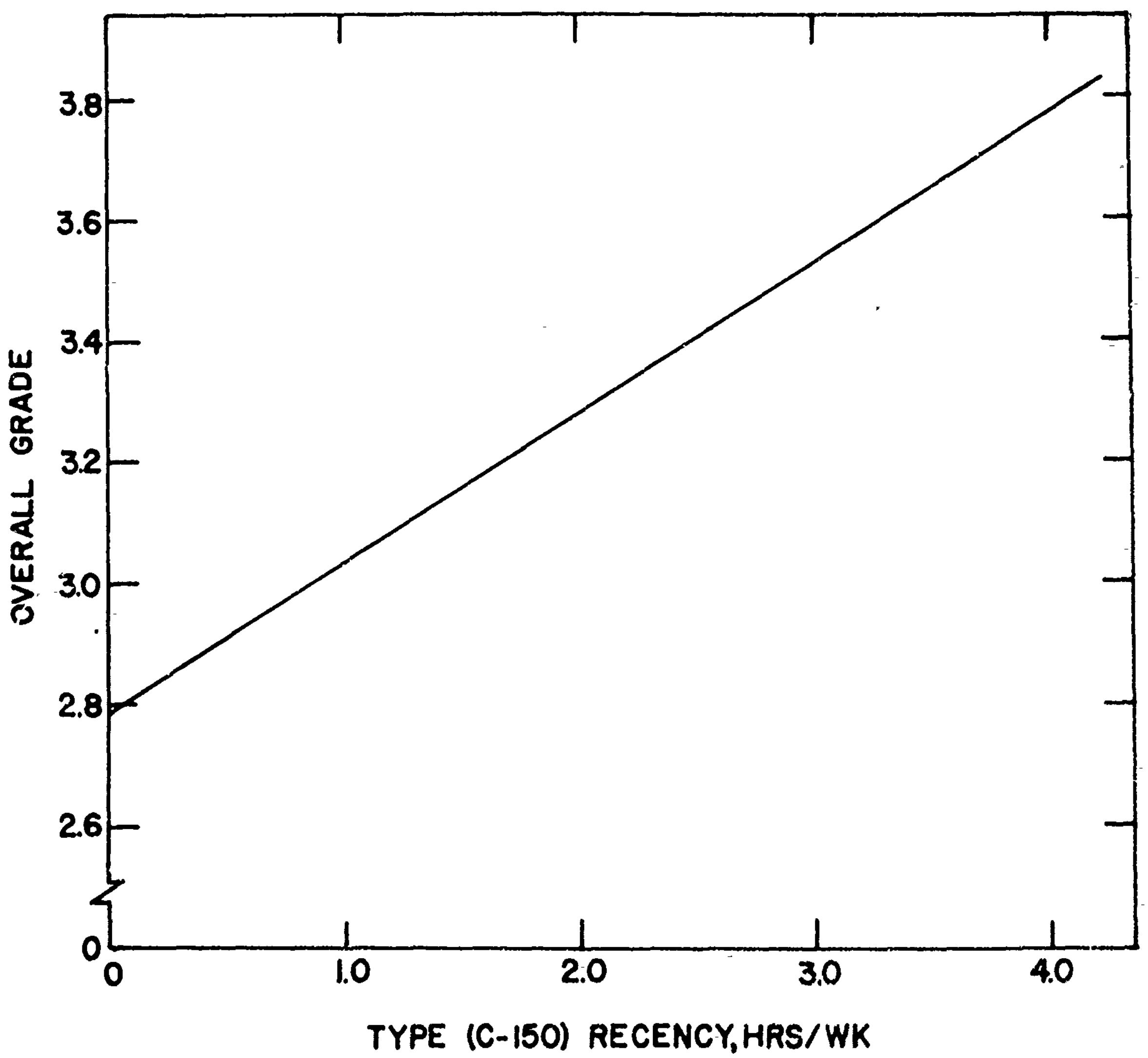
PILOT RECENCY PROGRAM

Appendix F-2

```
*

 W
C-FOCAL,1969

01.10 E
01.11 A R;A C;S N=R*C
01.20 F I=1,N;A V(I);S T=V(I)+T
01.21 T !!!
01.30 F I=1,R;D 2
01.40 F I=1,C;D 3
01.45 F I=1,R;D 7
01.50 F I=1,R;D 4
01.60 F I=1,C;D 6
01.70 T %3,!!,"  GRAND TOTAL",T
01.80 T %6.03,!!,"     CHI SQUARED",X;T %3,"  DF",(R-1)*(C-1),!!
01.90 Q

02.10 F J=<(I-1)*C+1>,<(I-1)*C+C>;S R(I)=R(I)+V(J)

03.10 F J=0,R-1;S C(I)=C(I)+V(I+J*C)

04.10 T %3,!!,"ROW",I,"   ROW TOTAL",R(I)
04.20 T %4.04,"  % OF GR TOT IN ROW ",R(I)/T,!!
04.30 F J=1,C;D 5

05.10 S P=<R(I)*C(J)>/T;S H(J)=V<(I-1)*C+J>
05.20 T %2,"    COL",J,!
05.30 T %3,"       ACTUAL",H(J);T %6.03,"  EXPECTED",P,!
05.40 S G(J)=<H(J)-P>↑2/P;S X=X+G(J)
05.50 T %6.03,"       CELL CHI SQ",G(J),!
05.60 T %4.04,"       % COL",H(J)/C(J)," % ROW",H(J)/R(I),!
05.70 T %4.04,"       % TOTAL",H(J)/T,!!

06.10 T %3,!,"COLUMN",I,"  TOTAL",C(I)
06.20 T %4.04,"  % OF GR TOT IN COL ",C(I)/T

07.10 F J=<(I-1)*C+1>,<(I-1)*C+C>;T %3,V(J)
07.20 T !
*
```

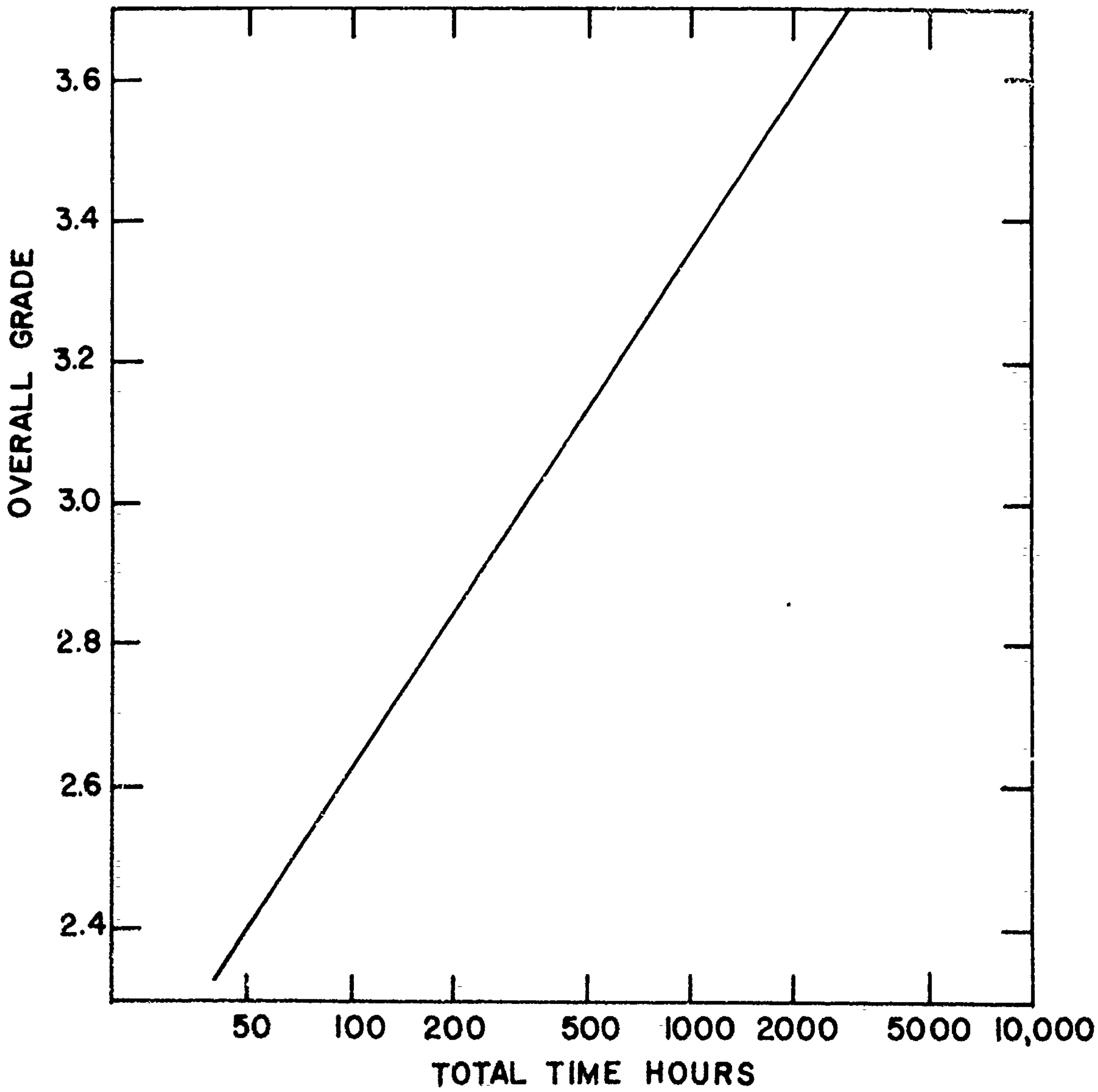
χ^2 CONTINGENCY TABLE ANALYSIS

Appendix F-3



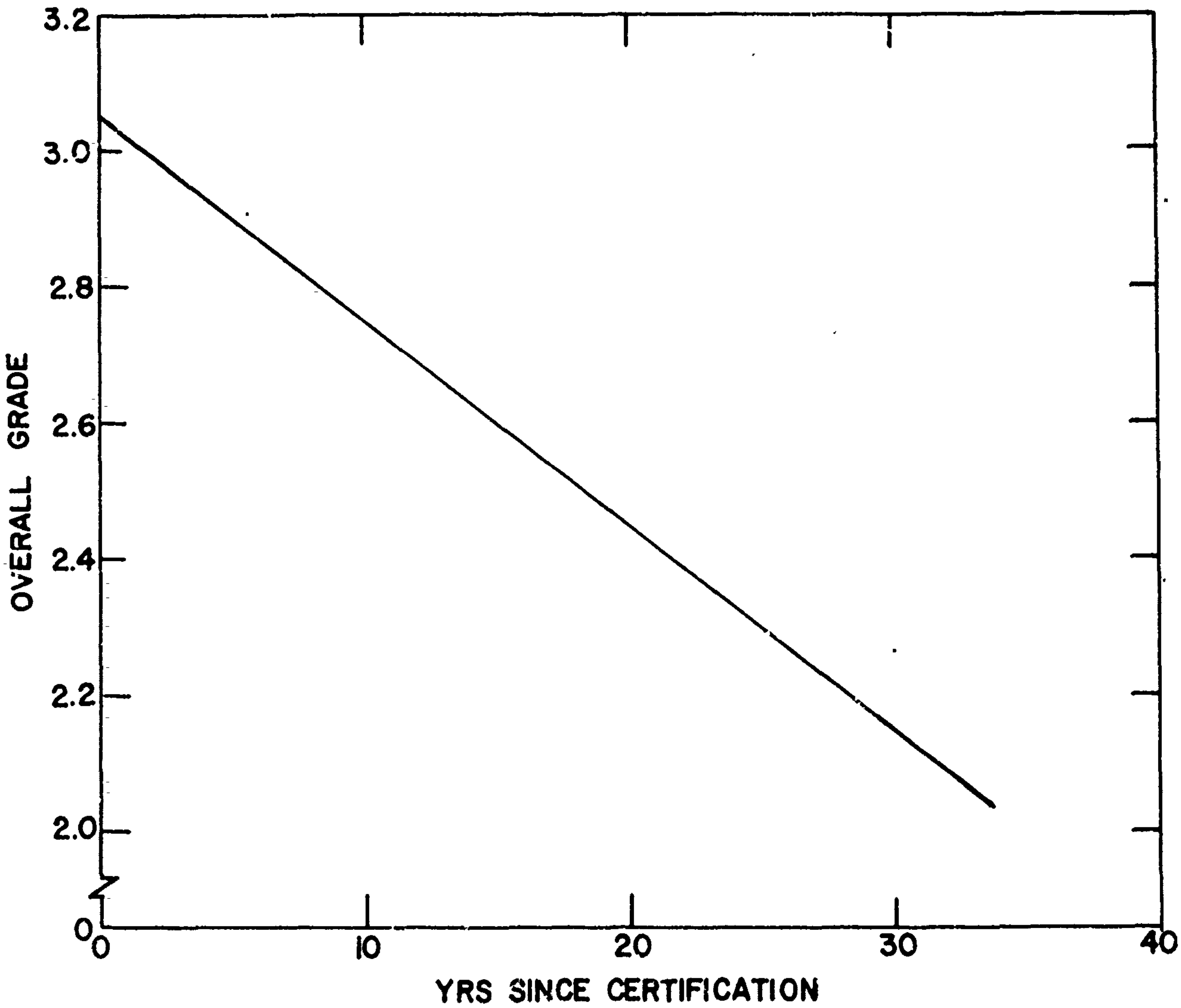
OVERALL GRADE VS. TYPE (CESSNA 150) RECENCY

Figure 6



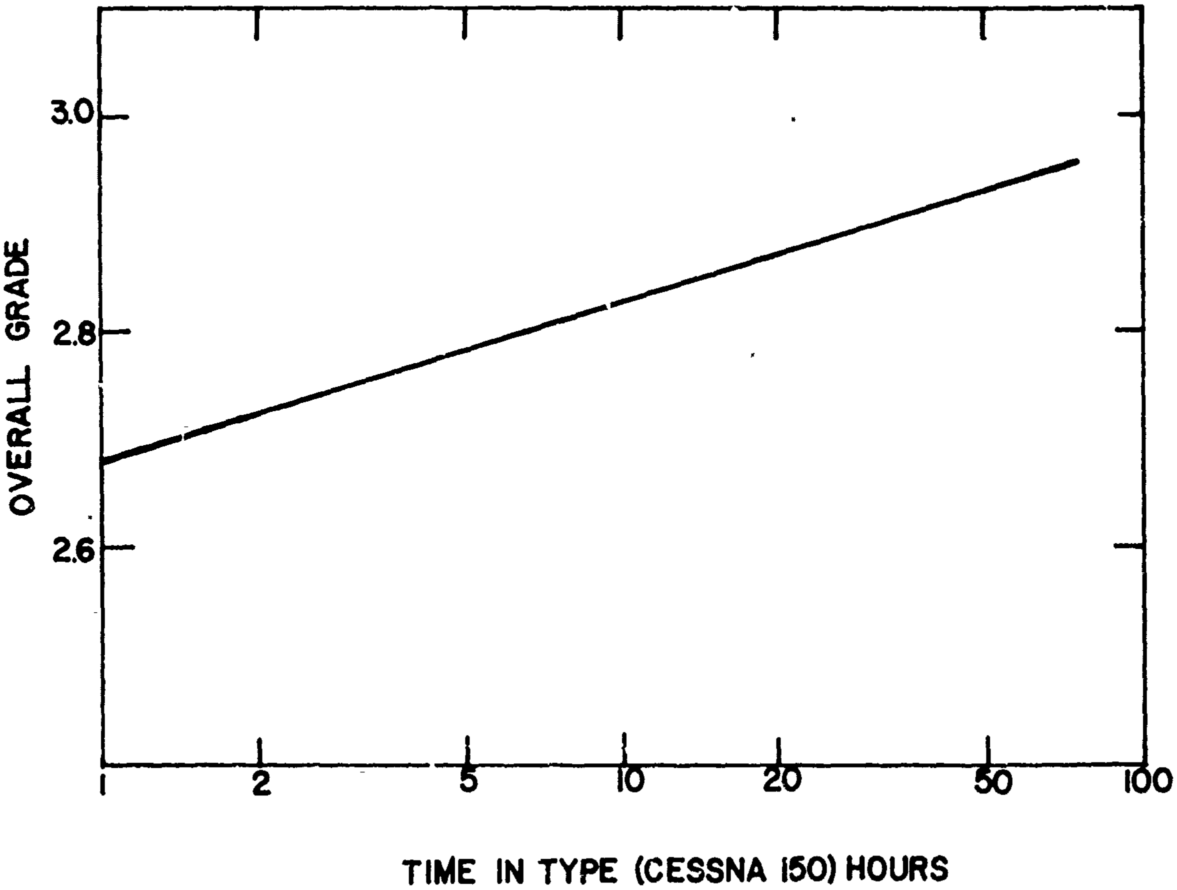
OVERALL GRADE VS. TOTAL TIME

Figure 7



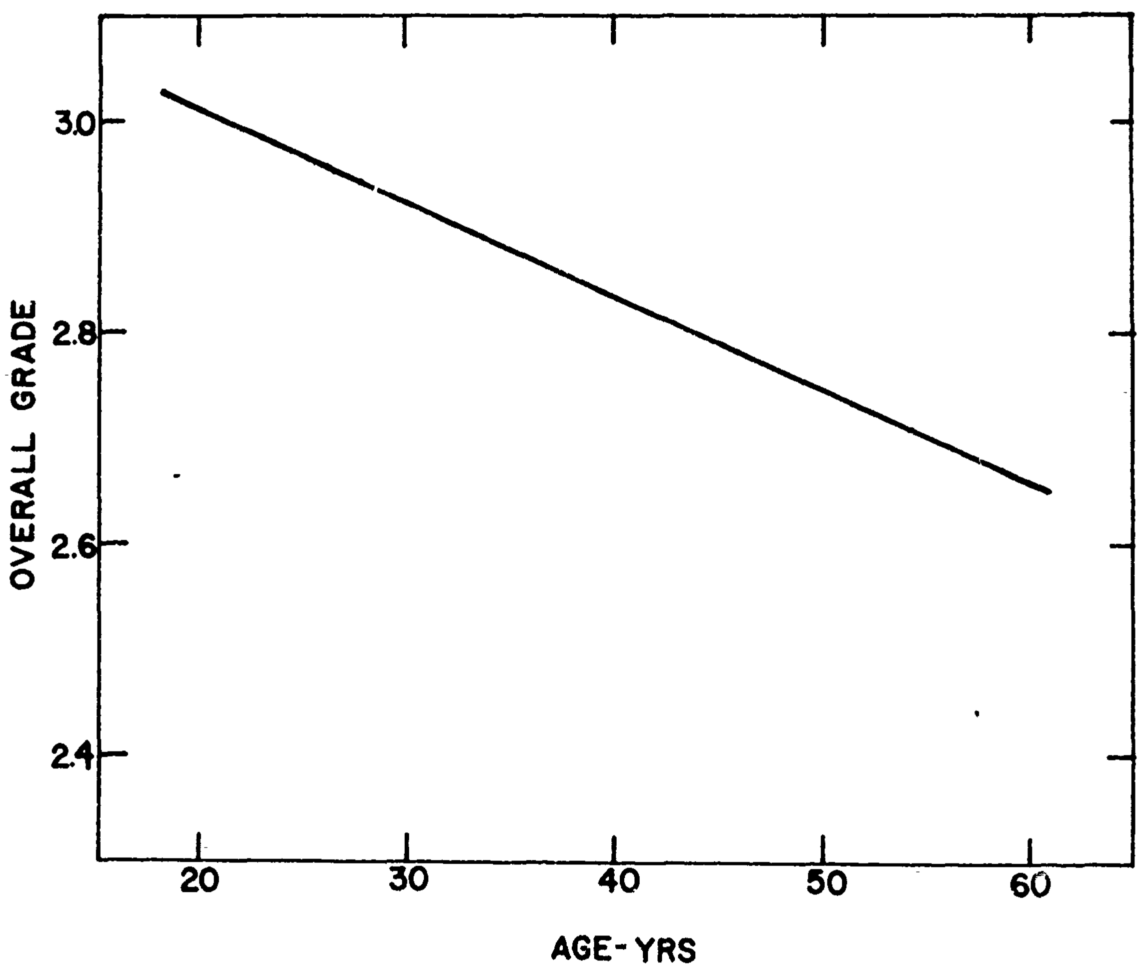
OVERALL GRADE VS. YEARS SINCE CERTIFICATION

Figure 8



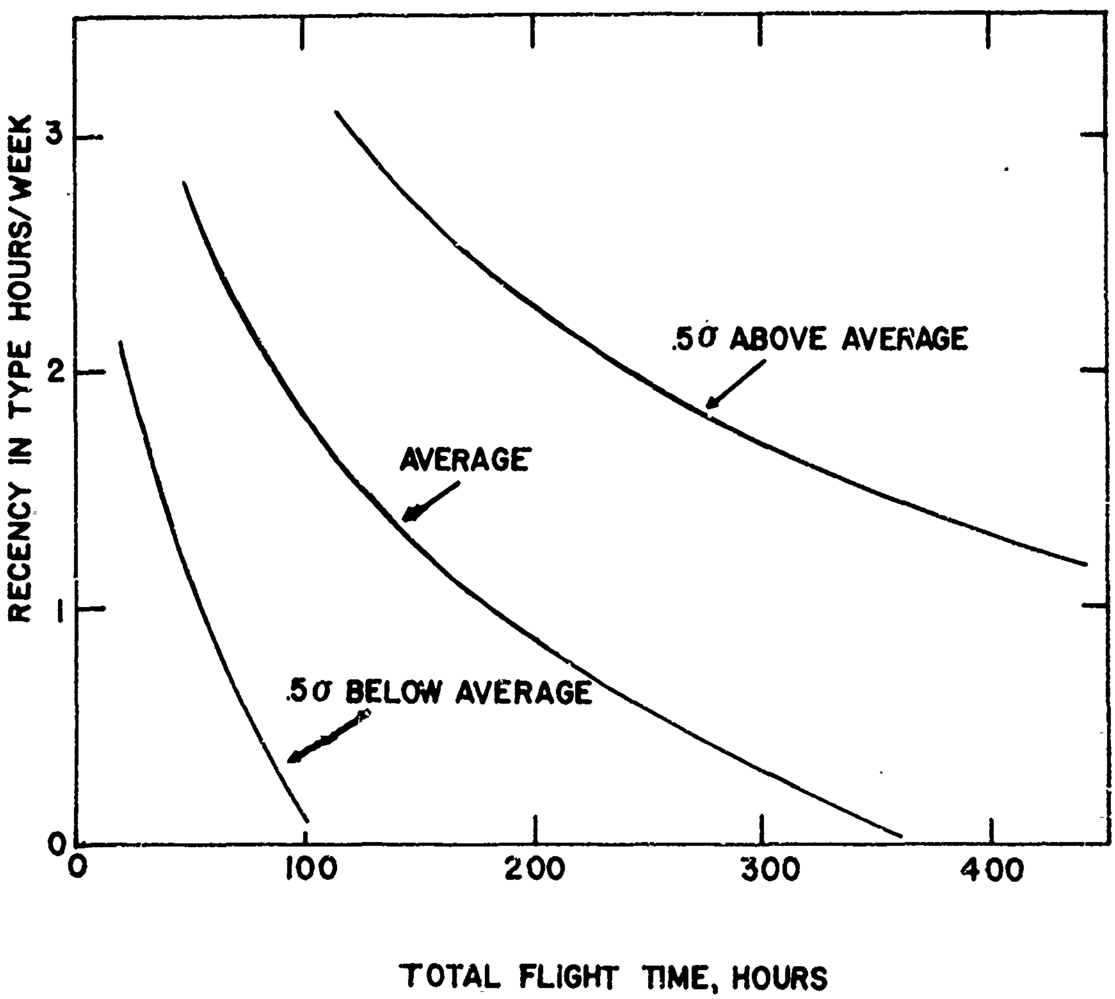
OVERALL GRADE VS. TIME IN TYPE (CESSNA 150)

Figure 9



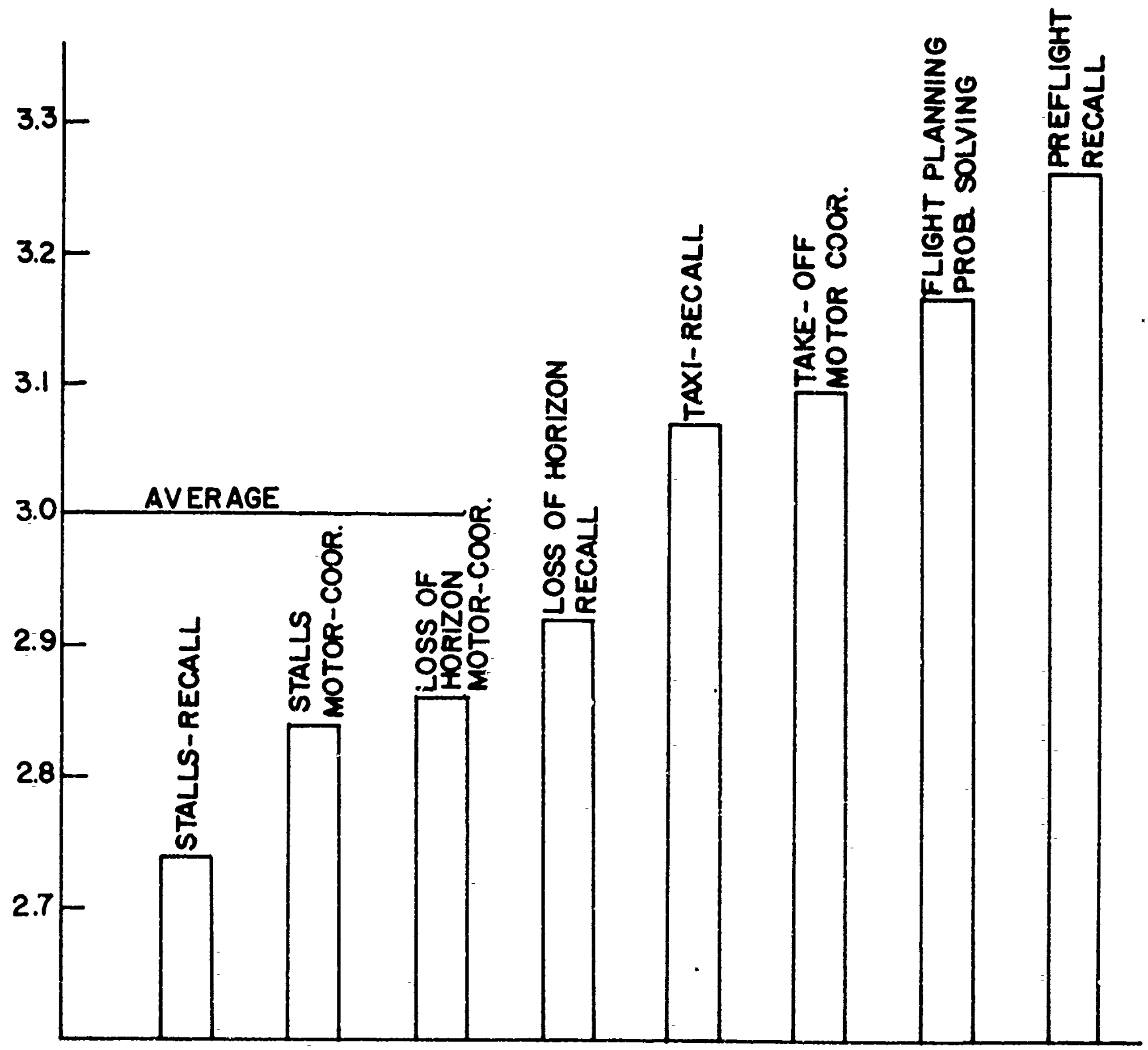
OVERALL GRADE VS. AGE

Figure 10



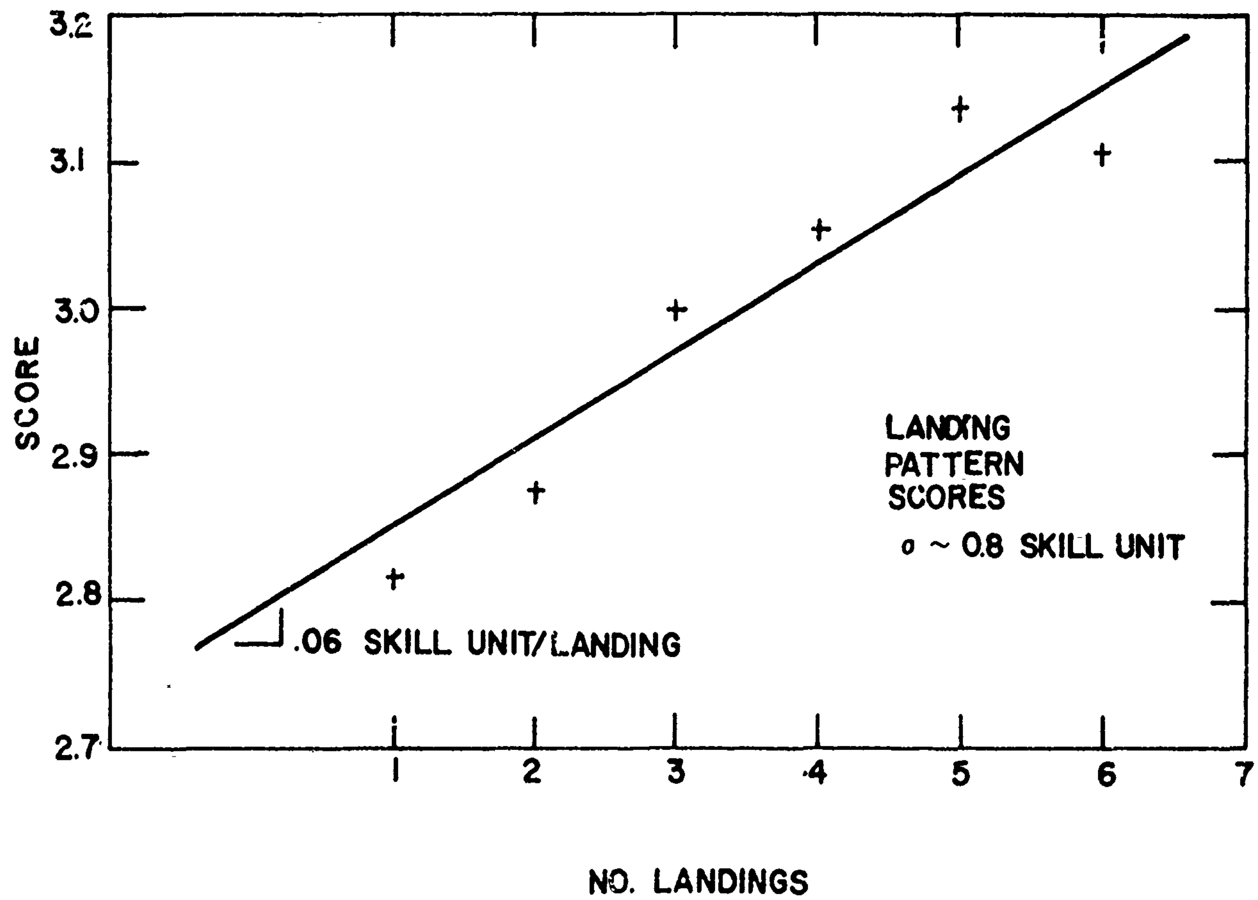
RECENCY IN TYPE VS. TOTAL FLIGHT TIME

Figure 11

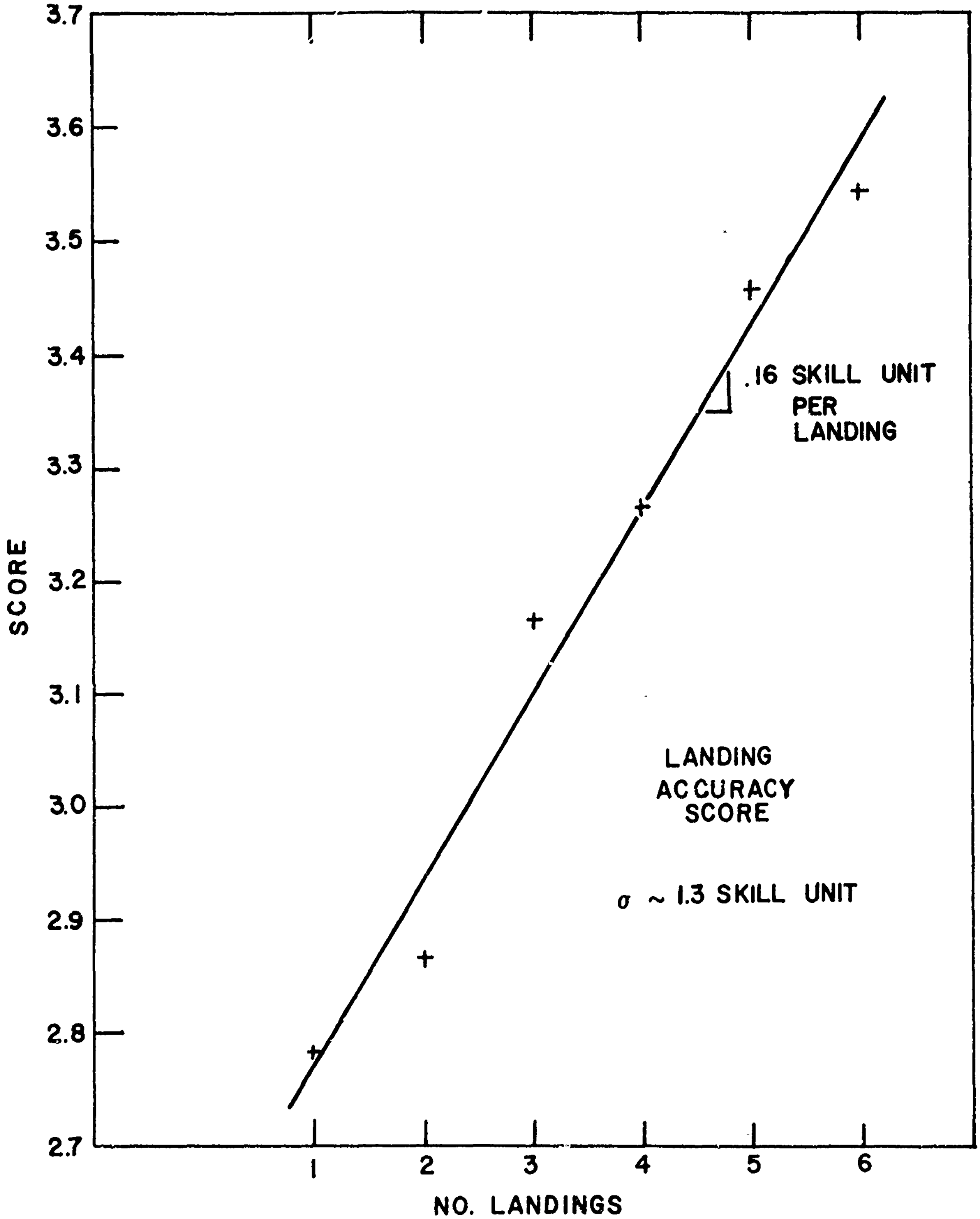


FOUR HIGHEST AND FOUR LOWEST SKILL SCORES

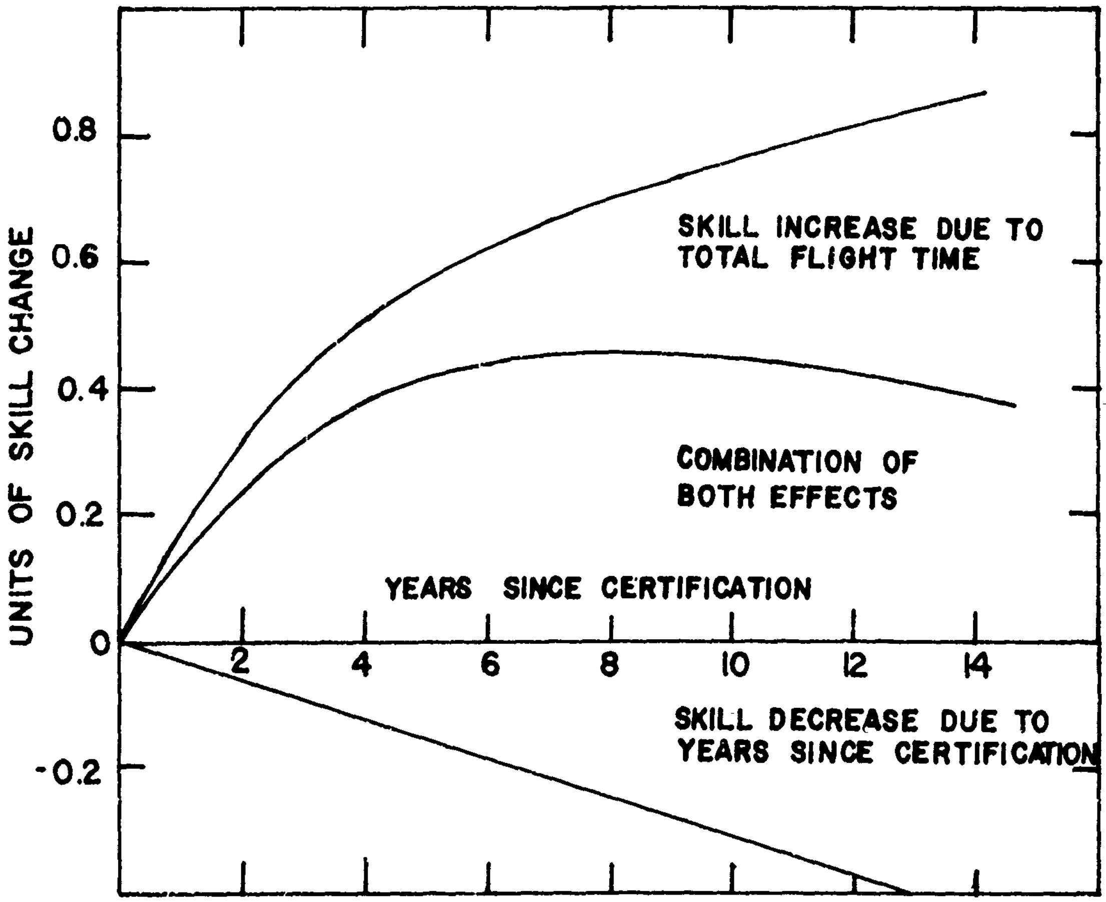
Figure 12



MEAN LANDING PATTERN SCORE VS. LANDING
Figure 14



MEAN LANDING ACCURACY SCORE VS. LANDING
Figure 15



COMBINED EFFECT OF SKILL CHANGE DUE TO TOTAL TIME AND YEARS SINCE CERTIFICATION FOR PILOT WHO FLIES REGULARLY 100 HOURS PER YEAR

Figure 16